The Effects of Knee Bracing on Reactive Agility Performance Among Healthy Soccer Players – A Pilot Study

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Abstract

Introduction: Soccer is the most popular sport in the world. The increase in the sport's popularity is paralleled with an increased prevalence of knee injuries. Knee braces are commonly worn in athletic populations to prevent knee injuries. The biomechanics of wearing knee bracing have been well documented, with studies showing reduced vertical ground reaction forces. One concern with wearing knee braces, however, has been the possible effect on sports performance, the research examining this topic has been confounding. Some studies have shown that agility time has improved during an agility T-test, while others have shown no change in agility time. To date, no studies have examined the effects of knee bracing on reactive agility performance. The measurement of neuromuscular activity is known as electromyography. Electromyography is also another area of interest with regards to sport performance. To date, there is limited research on the effect of the application of a knee brace on the electromyography of various lower extremity muscles during cutting maneuvers. More specifically, no studies have explored the effect that knee braces may have on the peak muscular activation on the gluteus medius during an agility task. Therefore, the purpose of this pilot study was to examine differences between braced and non-braced soccer players on measures of reactive agility time (s), and EMG activity (% MVC) of the GM, BF, and VL during the acceleration and change of direction phases of the Y-shaped reactive agility test.

Methods: Twenty four physically active individuals (14 male and10 female) completed the pilot study. Participants completed a Y-shaped reactive agility test under two conditions including wearing no knee brace and wearing a DonJoy® Playmaker II knee brace on their dominant leg. Agility test time (seconds) and peak EMG muscle activity as a percent of the participants maximal voluntary contraction (%MVC) of the gluteus medius (GM), vastus lateralis (VL), and the biceps femoris (BF) of the braced leg was measured. The Y-shaped reactive agility test was separated into the acceleration phase and the change of direction phase. A three-way repeated measures ANOVA was conducted to compare the independent variables (brace condition, phase, and muscle type) on the dependent variable (reactive agility time). If no interaction effect was found, the main effects of brace condition, agility phase, and muscle type separately as well as two way significant interactions were examined. A paired samples t-test was also conducted to compare the type of brace conditions on measures of reactive agility time. The alpha level was set at $p<.05$ for both statistical analyses.

Results: The three-way repeated measures ANOVA revealed no statistically significant interaction effect between the three independent variables (brace condition, phase, and muscle type) on peak EMG activity during the Y-shaped reactive agility test, $F(2,46)=2.296$, $p=.124$. A two-way ANOVA comparing phase and muscle type revealed a statistically significant difference in peak EMG activity during the Y-shaped reactive agility test with a large effect size, $F(2,22)=6.565$, $p=.006$, $\eta^2=.374$. Bonferroni pairwise comparisons analysis revealed a statistically significant increase in peak EMG activity in the GM muscle in the change of direction phase compared to the acceleration phase with a large effect size, $F(1,23)=21.59$, $p=.0001$, $\eta^2=.484$. A two-way ANOVA examining brace condition and muscle type did not reveal a statistically significant change in peak EMG activity during the Y-shaped reactive agility test, $F(2,22)=1.451$, $p=.256$.

Conclusion: The current pilot study identified that higher muscle activation was found in the GM and BF muscles during the change of direction phase compared to the acceleration phase. The application of a hinged prophylactic knee brace, however, did not significantly affect agility time and the muscle activity in the GM, BF, and VL muscles during a Y-shaped reactive agility test. Although no significant differences were found from a performance perspective, future researchers can build on the results from the current pilot study and incorporate different movements soccer players regularly perform with a larger sample size.

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Over the past two years I have had the privilege to complete a Master's degree, something which many strive to obtain. It is difficult to put into words what graduate school really is. The excitement of seeing your project come to life and frustration over the endless critiques and criticisms, are two sides of the same coin. The difficult journey that is grad school is not only challenging academically but also mentally. The most difficult part of this degree, for me, was to keep going, but I am thankful for those around me that helped me complete this monumental achievement. First, I would like to thank my parents, Angela and Dominic for their continued personal support (and financial) support; without your contributions I would not be where I am today. I would also like to take this opportunity to thank the Canadian Institutes of Health Research for being awarded the Fredrick Banting and Charles Best Canada Graduate Scholarship. The proceeds from the award were value in helping me complete this project. Being able to be a recipient for a scholarship named after those who discovered insulin is truly an honour. I would also like to thank Dr. Sanzo for his guidance, expertise and keen eye throughout my Master's degree. I would also like to thank my committee members, Dr. Zerpa and Dr. Kivi, for their valuable input and guidance on the project.

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"I have no special talent. I am only passionately curious."

Albert Einstein

"We keep moving forward, opening new doors, and doing new things, because we're curious and curiosity keeps leading us down new paths."

Walt Disney

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List of Abbreviations

%MVC – Percent of maximal voluntary contraction

ACL – Anterior cruciate ligament

BF – Biceps femoris muscle

CAD – Canadian dollar

cm – Centimeters

EMG – Electromyography

FKB – Functional knee brace

GM – Gluteus medius muscle

GRF – Ground reaction force

kg – Kilograms

km/h – Kilometers per hour

m – Meters

MCL – Medial collateral ligament

m/s – Meters per second

mV – Millivolts

PAR-Q+ – Physical activity readiness questionnaire

s – Seconds

USA – United States of America

USD – United States dollars

VL – Vastus lateralis muscle

VM – Vastus medialis muscle

Chapter One: Introduction

Overview

The risk of a sport-related knee injury ranges from 13% to 71% of all injuries across the globe (Agel et al., 2007; de Loës et al., 2000; Delfico & Garrett, 1998; Houck, 2003; Oates et al., 1999). Soccer requires increased demand on a player's knees, and the sudden change in direction, rapid cutting maneuvers, and moderate contact and collisions can put the player's knee joint at risk of injury (Delfico & Garrett, 1998). Globally, soccer is the most popular sport, growing from approximately 240 million players in 2012 (Junge & Dvorak, 2004) to 270 million players in 2019 (Roth & Osbahr, 2018; Sadigursky et al., 2017). As of 2019, it includes a minimum of 128,983 professional soccer players (Fédération Internationale de Football Association, 2019). The increase in the sport's popularity is paralleled with an increased prevalence of knee injuries. Video analysis of professional soccer players revealed that the most common playing situations for non-contact knee injuries occurred in pressing, followed by kicking and heading, respectively (Grassi et al., 2017; Roth & Oshahr, 2018; Walden et al., 2011; Walden et al., 2015). Anterior cruciate ligament (ACL) injuries, for example, are among the most common knee injuries in soccer and are especially vulnerable while performing these movements (Gottlob et al., 2019; Patel et al., 2019). An ACL injury can have many adverse effects on an athlete's neuromuscular characteristics, including changes to the somatosensory system, muscle activation patterns, muscle strength, muscle size, and proprioception (Ingersoll et al., 2008). Due to the adverse side effects of knee injuries, physicians regularly prescribe athletes to wear a protective knee brace when returning to play, especially after a surgical procedure (Decoster & Vailas, 2003; McRae et al., 2011). Knowledge about the knee joint anatomy may provide insight into what structures allow the joint to remain stable.

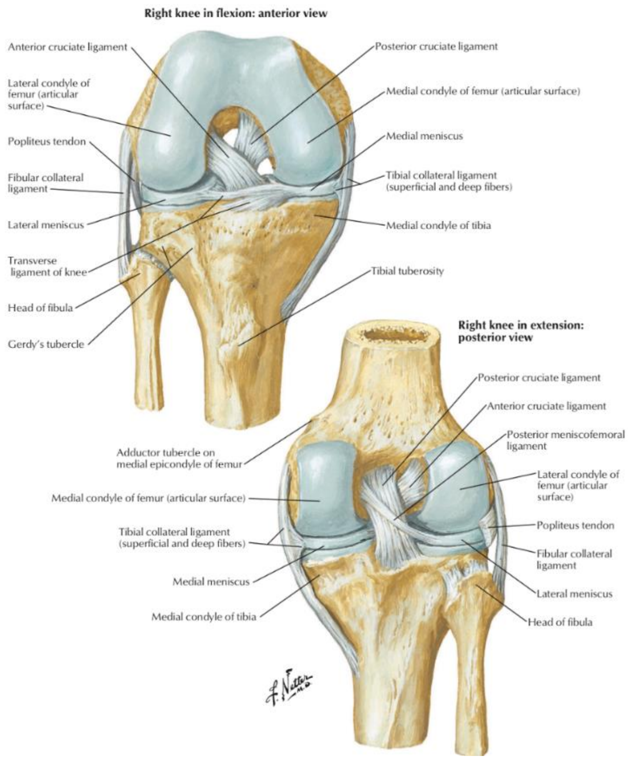
The Knee Joint

The knee joint is a large, synovial joint comprised of three articulations within the joint capsule. The bony structures that make up the knee joint are the femur, patella, tibia, and fibula. The two-weight bearing condylar articulations are the tibiofemoral joints and the third articulation is the patellofemoral joint (Anderson, 2017). The tibiofemoral joint, often referred to as the knee joint proper, is a modified synovial hinge joint that allows for flexion and extension of the knee in the sagittal direction with limited rotational movements in the frontal direction (Anderson, 2017). Each of these articulations and boney structures are stabilized via a combination of soft tissue, ligamentous and cartilaginous structures. These bones and ligaments encapsulate the synovial cavity (Tortora & Nielsen, 2014).

The patellofemoral ligament connects the patella to the femur and tibia. The ACL, posterior cruciate ligament, medial collateral ligament (MCL), lateral collateral ligament, posterior menisco-femoral ligament, and meniscus make up the soft and fibrous tissues supporting and stabilizing the knee joint (see Figure 1). The lateral collateral ligament, MCL, posterior collateral ligament, and ACL originate on the femur and attach to the tibia, except the lateral collateral ligament, which attaches to the fibula.

Figure 1

The knee joint.



Note. The knee joint. This figure displays the location of the structures that make up the knee joint. Adopted from "Atlas of human anatomy (6th Ed.)," by F. H. Netter, p. 496.

The role of the knee ligaments includes the passive guidance of the bones during normal joint function and in the stabilization of the joints (e.g., prevention of abnormal bony displacements) during the application of extrinsic loading (Magee et al., 2007). When a ligament is torn, bones can no longer maintain a normal kinematic relationship and displace abnormally during extrinsic loading, further enhancing the risk of osteoarthritic development (Magee et al., 2007). Abnormal displacement serves as one of the main reasons knee braces are often prescribed after a ligament injury.

Knee Bracing

Knee bracing is a common practice in sport to protect the knee joint and prevent further damage to the joint and soft tissue structures (Yeung et al., 2011). In the National Collegiate Athletic Association Division One, football teams usually mandate the use of prophylactic knee bracing with a league participation rate near 100% (Borden, 2017; Chengelis, 2016). Custom-fitted functional knee braces (FKB) can cost $1,600 Canadian dollars (CAD) per brace (Torontophysiotherapy, n.d.). This price pales in comparison to the median healthcare utilization cost for ACL reconstruction of $13,403 United States dollars (USD; Herzog et al., 2017). A knee brace can help decrease the overall cost to both the individual and the healthcare system by reducing the potential of a sprain or retear of the reconstructed ligament. Sprain and retearing can lead to complications, such as osteoarthritis, which will likely require future surgical intervention, further increasing the financial burden on both the individual and the healthcare system (Herzog et al., 2017). Therefore, the potential cost savings of a knee brace cannot be ignored in knee injury prevention and rehabilitation.

As of 2013, based on the annual incidence of 350,000 ACL reconstructions in the United States of America (USA) per year, the annual cost attributable to the long-term development of osteoarthritis was $4.24 billion USD for rehabilitation programs and $2.78 billion USD for ACL reconstruction surgery (Mather et al., 2013). The mean lifetime cost to society for a typical patient undergoing ACL reconstruction in the USA was $38,121 USD compared to $88,538 USD for rehabilitation alone (Mather et al., 2013). Similar costs can also be attributable to this injury and treatment options in other countries including Canada. Surgical intervention appears to be the more economical treatment for ACL injuries compared to rehabilitation alone. Patients who undergo ACL surgery are also typically prescribed a knee brace (Decoster & Vailas, 2003; McRae et al., 2011) with many different types of knee braces available.

Types of Knee Braces

There are several types of knee braces that currently exist, that can either be custom fitted or generic. The three main types of braces include rehabilitation, prophylactic, and functional braces. Rehabilitation knee braces allow for a protected range of motion of an injured knee post-surgery (Rishiraj et al., 2012). Rehabilitation knee braces are only worn post-surgery, typically for no longer than two months, and are not worn during activities that are more strenuous than walking due to the bulky nature of the knee brace (see Figure 4; Rishiraj et al., 2012). Prophylactic knee braces are most recognizable to the general population because they are regularly found on store shelves. Prophylactic knee braces are often referred to as knee sleeves and are designed to reduce or prevent knee injuries (Rishiraj et al., 2012; Wirth et al., 1990). Prophylactic braces can also be adapted to have a hinge mechanism similar to FKBs. The hinge mechanism limits hyperextension to protect the ligaments in the knee. Conversely, FKBs are mainly custom-made and designed to provide stability for an unstable knee joint during physical activity (American Association of Orthopedic Surgeons, 1987; Wirth et al., 1990). Of those three types, the most popular types of knee braces in sports are the prophylactic softshell, such as the Donjoy® Hinged Lateral "J" (see Figure 2), and functional hard shell knee braces, such as the Donjoy® Defiance® III (see Figure 3; Bodendorfer et al., 2019; Najibi & Albright, 2005; Rishiraj et al., 2012).

Figure 2.

Donyjoy® Hinged Lateral "J".

Note. This image displays an example of one of many prophylactic knee braces on the market. Retrieved from https://www.djoglobal.com/products/donjoy/hinged-lateral-j

Figure 3.

Donjoy® Defianec® III.

Note. This image displays an example of a functional knee brace athletes may wear after ACL reconstruction to prevent ACL injuries in the future. Retrieved from https://www.djoglobal.com/products/donjoy/defiance-iii-knee-brace

Figure 4

T Scope ® Premier Post-Op Knee Brace

Note. This image displays a typical example of a post-operative rehabilitation knee brace following ligament reconstruction to the knee joint. Retrieved from https://www.breg.com/products/knee-bracing/post-op/t-scope-premier-post-op-knee-brace/

Prophylactic Knee Braces and Injury Prevention. During the 1970s, braces such as the Lenox Hill® brace (Lenox Hill® Hospital Brace Shop, New York, NY, USA) were seen as too bulky and restrictive during competition (Rishiraj et al., 2012). From 1979 to 1985, several brace manufacturers released knee braces claiming to prevent MCL and ACL injuries. These claims were largely anecdotal and not necessarily based on scientific studies (Garrick & Requa, 1987). From 1985 to the late 1990s, research prioritized the efficacy of prophylactic knee bracing to minimize ligament injuries. The reported research findings and conclusions regarding the use of prophylactic knee braces during this period were mixed. When examining studies focusing on the impact of prophylactic knee braces on ACL injuries in American football, no statistically significant difference between braced and non-braced subjects was found (Jackson et al., 1991; Sitler et al., 1990). Hewson et al. (1991) also found no statistically significant difference in exposure to injury in American football players wearing a prophylactic knee brace compared to players who did not. Conversely, Sitler et al. (1990) did find that wearing a prophylactic knee brace reduced the number of MCL injuries in intramural football players.

Prophylactic knee braces offer an advantage over FKBs in that they are more cost-effective, ranging from $20 CAD to $300 CAD. The cost-effectiveness of prophylactic knee braces makes them an attractive option for the amateur soccer players and sports organizations on small budgets. The American Association of Orthopedic Surgeons stated that a prophylactic knee brace reduced contact forces sufficient to cause medial joint line opening by 20-30% to the lateral side of the knee. These results suggest prophylactic knee braces can help reduce contact forces at the knee joint. Prophylactic knee braces may be an affordable alternative for individuals who cannot afford more expensive custom-fitted FKBs. Although a more affordable option, athletes remain reluctant to wear knee braces because of the perceived impediment to performance (Albright et al., 1994a; Albright et al., 1994b; Greene et al., 2000; Najibi & Albright, 2005; Paluska & McKeag, 2000).

Studies have been mixed when examining the reduction of knee injuries using prophylactic knee braces. Research looking solely at MCL injury prevention in collegiate American football players have reported no statistically significant change in the rate of MCL knee injuries (Hewson et al., 1986; Rovere et al., 1987; Zemper, 2009). Rovere et al. (1987), for example, looked at MCL and ACL injury prevention in the same population and also found no change in MCL injuries. These results were based on knee injuries per number of exposures, sports days lost due to the knee injury, and the degree of the injury. When examining prophylactic knee bracing in American football athletes, Albright et al. (1994a & 1994b) and Sitler et al. (1990) found a statistically significant decrease in MCL injury rates in players in ‘non-skilled’ positions (e.g., offensive and defensive linemen, tight-ends, and linebackers). Whereas skilled players (e.g., running backs, kickers, quarterbacks, and safeties) reported higher MCL injuries. In a systematic review, Najibi and colleagues (2005) found a decrease in MCL injuries while wearing a prophylactic knee brace in both practices and games, however, the decrease in MCL injuries was not statistically significant.

In contrast, two studies reported a statistically significant increase in the incidence of MCL injuries while using a prophylactic knee brace (Grace et al., 1988; Teitz et al., 1987). Other researchers have advocated for the use of prophylactic knee braces to protect against MCL injuries in collegiate football athletes (Albright et al., 1994a; Albright et al., 1994b; Salata et al., 2010; Sitler et al., 1990). These mixed results highlight the need for more research pertaining to prophylactic knee braces, not just in American football but across other sports.

Lundblad et al. (2019) examined the prevalence of MCL injuries in male soccer players from the elite clubs of the Union of European Football Association. They found that the layoff period was significantly longer for grade II MCL injuries in individuals who wore a prophylactic knee brace compared to grade II MCL injuries in players who did not wear a knee brace. The researchers were unable to discern if the longer layoff period was due to a more conservative approach by the various medical teams as a result of the player wearing a knee brace or if the knee brace prevented the player from progressing during their rehabilitation period. The main conclusion from the study was that knee injuries may be treated more conservatively by using a knee brace, resulting in an increased layoff time for the athlete. Functional knee braces are also widely used among athletes to prevent injury following an initial injury and the research on their use also needs to be highlighted.

Functional Knee Braces and Injury Prevention. Paulos et al. (1987) classified FKBs into two categories: post and strap FKBs and post and shell FKBs. Post and strap FKBs resemble rehabilitation knee braces with limited research on the use of these braces in athletes. Conversely, post and shell FKBs come in different types that can produce a valgus force (medial unloading) on the knee joint or correct varus misalignment (Sprouse et al., 2018). There is more research regarding post and shell knee FKBs, although the current available research mainly focuses on individuals with osteoarthritis (Duivenvoorden et al., 2015). Functional knee braces generally apply an external valgus force onto the knee joint, causing a reduction of the load on the medial compartment of the joint (Sprouse et al., 2018). Compared to conservative treatment, FKBs with medial unloading reported an increased benefit of reducing pain and increasing an individual's walking distance (Brouwer et al., 2006). When wearing a FKB over a 12-month period, the severity of subjective knee pain decreased when reported using a visual analogue scale ranging from 0 to 10, where 0 indicated no pain and 10 indicated the most severe pain (Brouwer et al., 2006). Visual analogue scales have been shown to have high validity and reliability in an adult population (Bird et al., 2016). Wearing FKBs has also been reported to increase knee function when measured using the Hospital for Special Surgeries Scale (Brouwer et al., 2006). The Hospital for Special Surgeries Scale is a self-reported scale used to assess the stability, mobility, and range of motion of the knee joint and the subjective pain experienced. This scale has been shown to have moderate to good reliability and validity in an adult athletic population (Marx et al., 2001). The higher the score indicates a more stable knee, greater range of motion, and lower subjective pain. In this study, the use of a FKB also resulted in an increase in self-reported walking distance of 1.25 kilometres (km; Brouwer et al., 2006).

In an eight-year prospective study, Lee et al. (2017) concluded that wearing a FKB for six months reduced the chances of a patient needing surgery by half compared to those who wore the brace for three months. Patients who wore the knee brace for two years were also less likely to require surgery at the eight-year follow-up period. In another study, Wilson et al. (2011) examined the effects of wearing a medial unloading knee brace in patients with osteoarthritis. The researchers interviewed participants at a mean time of 11.2 years from their initial surgery. The interviewer asked questions regarding the patients' functional mobility, pain, stiffness, and swelling. It was reported that when wearing FKBs, patients had increased functional mobility and decreased pain, stiffness, and swelling. These benefits were present in the short term (after 2.7 years) but not in the long term (after 11.2 years). This outcome may also be explained by the fact that the reported use of the brace decreased over time (Wilson et al., 2011). The use of a FKB is also commonly used in individuals who undergo ACL reconstruction surgery.

Individuals who undergo ACL reconstruction often face challenges regarding support and proprioception of the joint (Sugimoto et al., 2016). Instability is common after reconstructive surgery, and to reduce the risk of retearing the reconstructed ACL, physicians regularly prescribe a FKB to patients upon returning to physical activity (Sugimoto et al., 2016). It is believed that wearing a FKB provides mechanical support to the knee joint with some clinicians reporting that the use of a FKB improves joint stability via the external support provided (Sugimoto et al., 2016). A literature review by Sugimoto et al. (2016) examined the effects of a FKB on joint position sense in ACL reconstructed individuals. The results reported on the use of a FKB and its effect on joint proprioception, however, has been mixed. Of the three studies found on the topic of joint position sense in ACL reconstructed individuals, two demonstrated statistical significance for the effect of wearing a FKB on joint position sense.

One of the two crossover laboratory studies that demonstrated statistical significance was by Birmingham et al. (2001), in which the researchers measured centre of pressure values during a 10 seconds (s) balance test. Ground reaction forces (GRF) represent the force exerted by the ground on the foot when the foot contacts the ground. The researchers examined participants who had ACL reconstruction and wore a custom-fitted FKB post-surgery (DonJoy® Generation II versus the Lenox Hill® Custom 2) compared to those who had ACL reconstruction and did not wear any knee braces following surgery. Participants performed both a single limb balance test and a hopping test (Birmingham et al., 2001). The single limb balance test was completed with the participant’s eyes open and closed, while the hop test was conducted on a flat surface versus a foam surface. Participants completed both tests with and without a knee brace. The results revealed lower centre of pressure values in the anteroposterior direction when performing a single limb balance test on a stable surface with the participants' eyes open while wearing a brace compared to no brace (Birmingham et al., 2001). Lower centre of pressure values were associated with increased stability (Birmingham et al., 2001). This reduction in the centre of pressure values did not lead to more challenging conditions. These results align with previous literature examining the ability of ACL reconstructed participants completing a one-legged balancing task with their eyes open (Kuster et al., 1999). As with the centre of pressure measurements during balance tests, the proprioceptive effects of knee braces have also been called into question.

Unlike Birmingham et al. (2001), Risberg et al. (1999) did not find any statistically significant differences in threshold detection. The researchers examined proprioception via passive threshold detection during passive range of motion in patients who had a bone-to-bone patellar tendon graft ACL reconstruction and a healthy control. Threshold detection was measured by having participants sit on a chair with both legs flexed 15°. One leg was placed onto a machine that flexed the knee at a velocity of 0.5°/s. Once the subjects detected motion, they pressed a button that would stop the test and the flexion angle for each leg was measured. Participants were then asked to identify the leg that moved and whether it was in flexion or extension (Rishberg et al., 1999). Participants completed the test both with and without a DonJoy® FKB (Rishberg et al., 1999). There was no difference in threshold detection values when wearing the brace compared to without the brace in both the ACL reconstructed and control groups (Risberg et al., 1999).

The final study Sugimoto et al. (2016) investigated was by Wu et al. (2001). The researchers examined the effects a FKB had on ACL reconstructed participants during joint angle reproduction tests. The researchers had participants reproduce knee-joint angles. Participants were blindfolded and one leg was passively flexed to a certain angle. The participant was then instructed to reproduce the angle with their other leg. This task was completed under three braced conditions: wearing a FKB (DonJoy®) or a mechanical placebo brace, compared to no brace. The researchers reported that subjects had better knee-joint-angle acuity in both the FKB and mechanical placebo condition than the no brace condition (Wu et al., 2001). Current literature regarding the effect of FKBs on knee-joint angle repositioning following ACL reconstruction appears to be beneficial for users, however, few orthopedic surgeons still choose not to prescribe a knee brace to their clients.

Following ACL reconstruction, athletes returning to sports currently have a 30-35% risk of sustaining a second ACL injury after returning to sport (Paterno et al., 2014; Webster & Feller, 2016). To improve knee biomechanics and reduce the risk of reinjury, FKBs are often prescribed by orthopedic surgeons to wear during athletic activity (Peebles et al., 2019). The literature surrounding the effects of FKBs on knee joint proprioception and injury prevention is contradictory. In a survey of orthopedic surgeons of the Canadian Orthopaedic Association (n=283), an estimated 45.2% never prescribed knee braces to their patients following ACL reconstruction. On the other hand, 26.7% prescribed braces for patients to wear 9-12 months following their return to sport, and 10% recommended wearing the brace indefinitely (McRae et al., 2011). One reason for the inconsistency of prescribing braces following ACL reconstruction may be the lack of objective evidence examining the impact of wearing a brace during the return to sport transition phase. While the prescription of knee braces following ACL reconstruction is not always widely agreed upon, the single leg hop test is commonly used to clinically evaluate an individual's readiness to return to sport following ACL reconstruction.

Single leg hop tests are often used clinically to evaluate neuromuscular control following ACL reconstruction and determine if a patient is ready to return to sport (Barber-Westin & Noyes, 2011). The single leg hop test involves the participant supporting themselves on one leg with no external support and performing a hop to achieve maximum horizontal distance while landing on the same leg. Shorter single leg hop test distances on the surgical limb compared to the non-surgical limb are associated with an increased risk of sustaining a second ACL injury and increasing the likelihood of developing early onset knee osteoarthritis (Paterno et al., 2017; Wellsandt et al., 2018). Therefore, understanding the effect a FKB can play during a single leg hop test may provide necessary information into an athlete’s readiness to return to sport and their potential risk of reinjury. In a previous study, Mortaza and colleagues (2013) concluded that there was no effect on single leg hop symmetry when wearing a FKB in patients who were ACL deficient compared to non-braced ACL deficient and healthy control participants during a single leg vertical jump. These results indicated that FKBs did not significantly improve or impair the knee joint's force control or force generation capacity during a single leg jump test in ACL deficient and healthy control samples (Mortaza et al., 2013). One limitation of the study was that the researchers did not allow participants time to become accustomed to wearing the FKB. Time to become accustomed to wearing a brace is essential because previous research has demonstrated that, in healthy individuals, the negative impact of wearing a FKB on physical performance deteriorates with time as the individual becomes more accustomed and comfortable with wearing the brace (Peebles et al., 2019; Rishira et al., 2011). While a FKB appears to have no effect on the single leg jump test, researchers have questioned if these results will differ in soccer players during specific tests.

The Effectiveness of Knee Bracing in Soccer

Researchers and players have raised concerns over the effectiveness of knee braces during sports activities and their impact on performance (McDevitt et al., 2004; Najibi & Albright, 2005; Risberg et al., 1999; Rishiraj et al., 2009a). Dickerson et al. (2020) examined the effects of time since ACL reconstructive surgery and the effects of wearing a custom-fitted FKB on physical performance measures in female soccer players. Participants completed a modified agility T-test and a vertical jump test and it was found that wearing a knee brace did not hinder vertical jump performance and T-test time 6-9 months post surgery. Agility time improved in 24 of the 28 participants and vertical jump height improved in 20 of the 28 participants 9 months following surgery. The improvements in agility time and vertical jump height at follow up suggested that patients that had ACL reconstruction were more physically prepared for the athletic demands of their sport 9 months following surgery. Dickerson et al. (2020) also illustrated that agility was not negatively affected when wearing a brace at this time interval following surgery. These results suggested that female soccer players can expect no decrease in agility performance when wearing a custom-fitted FKB 6-9 months post-surgery (Dickerson et al., 2020). This time frame is roughly the same time frame soccer players typically return to play following ACL reconstruction (Roi et al., 2006; Schiffner et al., 2018; Walden et al., 2010; Zaffagnini et al., 2014). While research surrounding the use of knee braces on soccer players is limited, the biomechanics of knee bracing has been investigated thoroughly.

Biomechanics of Knee Bracing

An abundance of research has been published regarding the biomechanical effects of wearing a knee brace or sleeve. One function of a knee brace is to increase proprioception and knee flexion angle at landing during jump tasks via a resistance hinge mechanism that applies increasing resistance to the knee joint as it approaches full extension. (Birmingham et al., 2001; Wu et al., 2001; Yu et al., 2004). An increase in knee flexion angle at landing can help reduce the risk of a non-contact ACL injury (Yu et al., 2004). Increased knee flexion angle at landing reduces the forces the knee incurs as previous research has shown, forces at the knee joint are lower when the knee joint is flexed at least 20° compared to when the knee is positioned in full extension or hyperextension (Markolf et al., 1990). Increased forces on the knee joint increases the chances of sustaining a ligament injury (Markolf et al., 1990; Yu et al., 2004).

The effect of bracing on lower extremity kinetics, kinematics, and electromyography (EMG) are not clearly defined or understood. During jumping tasks, wearing a knee brace has been reported to result in reduced vertical ground reaction forces (GRF_z; Rishiraj et al., 2012) and increased knee flexion angle at landing (Liu et al., 2014; Yu et al., 2004). During cutting tasks, a maneuver involving a change of direction, wearing a knee brace has also been associated with lower GRFs (Dai et al., 2012; Jones et al., 2012; Liu et al., 2014). Ground reaction forces are a subfield of kinetics and research regarding GRFs in relation to knee braces has been investigated throughout recent years.

Kinetics and Kinematics During Athletic Performance

Kinetics

Kinetics refers to the study of movement by taking into account the forces causing the motion, such as shear, torque, and GRFs (Hall, 2015). Research examining the kinetics of wearing knee braces has been investigated by measuring GRF.

Ground Reaction Forces During Jumping. Ground reaction forces are based on Newton’s Third Law of Motion which states that when two objects interact, they apply forces to each other, creating an equal and opposite reaction (Hall, 2015). Regarding human movement, GRFs represent the grounds forces acting on bodily contact and can be measured in the vertical (GRF_z), anteroposterior (GRF_y), and mediolateral (GRF_x) directions (Nielson & Thorstensson, 1989). Due to the knee being positioned between the femur and the tibia, the two largest boney levers in the human body, the potential for torque at the knee joint is high (Hall, 2015). The knee joint is frequently under compression and shear forces during daily activities such as walking, running, and jumping (Hall, 2015). Reduced knee flexion angle after landing during jumping tasks increases the GRFs which increases the load on the knee joint and thereby increasing the risk of knee injury (Buff et al., 1988; Grood et al., 1984; Markolf et al., 1990; Smidt, 1973; van Eijden et al., 1985; Yu et al., 2004). Rishiraj et al. (2012) examined healthy individuals wearing a FKB with an incremental resistance hinge mechanism when landing from a 70 cm jump. The researchers found that the peak GRF_z were lower in the braced group compared to the non-braced group. These results indicated that a FKB could have potentially absorbed the GRFs or increased the knee flexion angle at landing, reducing the GRF_z and protecting the ACL from injury. During both instep and outstep kicking, GRF have been observed to be 2.5-2.7 times the average body weight, 0.2-0.3 times greater in the vertical direction, and 0.8 times greater in the mediolateral direction in skilled pubertal soccer players who trained for a minimum of five years compared to non-skilled players (Katis & Kellis, 2010). Thus, these results may only apply to experienced soccer players with at least five years of experience performing an instep or outstep kick.

Vertical ground reaction forces during landing can cause injury and become detrimental to an athlete, primarily if the jumps are performed repeatedly and the GRFs are high (McNair et al., 2000; Mizrahi & Susak, 1982; Ortega et al., 2010). Yu et al. (2004) examined stop jump height in healthy participants wearing a FKB. In healthy male and female recreational athletes using a DonJoy® 4titude (DonJoy® Orthopedics, LLC, Vista, California, USA) knee brace, there was no difference in approach speed and jump height when performing a stop jump task. These results were seen in both males and females, and the bracing conditions did not affect the results. Maximum GRF_y, GRF_x, and GRF_z were also not statistically different during the stop jump task between braced conditions (Yu et al., 2004). Females had significantly greater GRF_y, GRF_x, and GRF_z when normalized to body weight during the stop jump task than males in both the braced and non-braced conditions (Yu et al., 2004). The researchers also found that wearing the knee brace resulted in a significantly increased knee flexion angle at landing during the stop jump task in both males and females (Yu et al., 2004). While GRFs were not statistically significant between brace conditions, they were still lower in the braced condition. The researchers concluded that wearing the knee brace still served its purpose to reduce the load on the ACL during the landing phase because increased knee flexion angles at landing had been shown to reduce the risk of an ACL injury (Buff et al., 1988; Grood et al., 1984; Markolf et al., 1990; Smidt, 1973; van Eijden et al., 1985). Increased knee flexion angle at landing can help reduce the force the on the knee ligaments and the risk of sprain and tearing. Based on the study by Yu and colleagues (2004), if females can increase their knee flexion angles at landing from 22.3° to 27.6° and males from 27.4° to 32.5°, the decrease in anterior shear force on the tibia should significantly reduce the load on the ACL if all other conditions remained the same (Yu et al., 2004). Besides exploring the effect of knee bracing on jumping tasks, researchers have also investigated the effect of cutting maneuvers in athletes wearing a FKB.

Ground Reaction Forces during Cutting. Jones et al. (2016) examined the GRFs in female soccer players playing in the second tier of the English women's soccer league. Participants performed a 90° cut and a 180° pivot turn and the time to complete each task, lower limb joint angles, and GRFs were recorded. The authors found lower average GRF_z and GRF_x and increased lower limb joint angles in the penultimate contact phase (e.g., the second to the last phase) than in the final contact phase of both the cutting and pivoting tasks (Jones et al., 2016). These results suggested that the penultimate contact phase in cutting and pivoting plays a role in directional change and preparing the body for an optimal position for the final contact phase in both maneuvers (Jones et al., 2016). While increased lower limb joint angles are witnessed in the penultimate phases of cutting and pivoting, knee bracing has also been previously shown to increase knee joint flexion angle (Yu et al., 2004). Liu et al. (2014) investigated the effects of wearing FKBs with extension constraints in recreational basketball and volleyball players. It was reported that after four weeks of knee extension constraint training using a FKB, knee flexion angle during the 45° cutting manoeuvre significantly increased, while peak impact GRF_y significantly decreased (Liu et al., 2014). At the end of the eighth week, the knee flexion angle was greater, and peak impact GRF_y was lower than their baseline measurements taken at week one, even after discontinuing brace use at week four. These results suggested that the effects of using a FKB with a knee extension constraint mechanism were at least partially retained over the long term (Liu et al., 2014). The results also indicated that wearing a FKB with knee extension constraints may be a valuable tool for the prevention of ligament injuries in the knee, especially ACL injuries during sports (Liu et al., 2014).

Schroeder and Weinhandl (2019) reported no statistical difference in peak GRF_x, GRF_y, and GRF_z directions and initial contact knee flexion and peak knee flexion between sexes when using an Ultra Zoom® hinged ankle brace during a 45° cutting movement. Marans et al. (1991) measured both objective and subjective performance measures in three off-the-shelf FKBs, and three custom-fitted FKBs in 10 ACL deficient participants during acute angle cutting. The acute angle cutting test had participants cut between multiple pylons placed 2 m apart from each other. The agility test consisted of participants running through tires in a straight line. Acute angle cutting time tended to be lower when wearing the braces compared to not wearing a brace (Marans et al., 1991). Only two custom-fitted FKBs (the Generation II Polyaxial Knee Cage and Lenox Hill® Derotation Brace) provided statistically significant improvements in the acute angle cutting time and agility test time and how stable the knee felt during activity (Marans et al., 1991). These braces provided the most improvements during functional tasks, although further research into the effects of long-term brace wear is needed (Marans et al., 1991).

Dai et al. (2012) had patients who had ACL reconstructive surgery perform a 35° side-cutting task both with and without a knee brace. They found that ACL reconstructed knees demonstrated less peak impact GRF_z, peak propulsion GRF_z, and peak knee extension torque when compared to the non-surgical limb. These results were observed during both the braced and unbraced conditions (Dai et al., 2012). The authors also noted that adolescent participants had decreased knee flexion angle at the time of cutting. These results appeared to be contradictory to previous literature regarding increased knee flexion range of motion on the surgical side compared to the non-surgical side (Ingersoll et al., 2008). It is believed that the change in knee flexion could have resulted from less fear of landing on the injured limb with the added support from the FKB (Dai et al., 2012).

The GM muscle is responsible for the abduction of the hip (Anderson et al., 2017). As a hip abductor muscle, the GM muscle contracts to stabilize the pelvis when in single leg support during walking, running, and cutting (Anderson et al., 2017; Maniar et al., 2019). A study by Maniar and colleagues (2019) examined the muscular contribution of lower limb muscles during the support and breaking and propulsion phases of a rapid sidestep cutting maneuver. Eight male participants completed the study, which involved performing two single leg hops and then quickly cutting at a 45° angle to either the left or right upon landing from the second hop. The researchers found that medial acceleration of the centre of mass was generated by the gluteus maximus and GM muscles (Maniar et al., 2019). The researchers found that by contributing to the medial GRF, the gluteus maximus and GM muscles were the most responsible for accelerating the body's centre of mass towards the desired cutting direction (Maniar et al., 2019). The researchers determined that these muscles were the dominant contributors to redirecting the centre of mass towards the direction of travel during the cutting movement (Maniar et al., 2019). The effects a knee brace has on the GM muscle's ability to redirect the centre of mass is currently unknown.

The research by Jones et al. (2016) highlighted that the effects a FKB had on GRFs during the penultimate contact phase. Wearing the FKB may play a role in lowering knee joint loads during the final contact phase where knee ligament injuries commonly occur, especially during cutting and pivoting maneuvers. Therefore, the use of a FKB may be beneficial in reducing the risk of knee injuries in sports such as soccer that require rapid and frequent cutting and pivoting maneuvers (Delfico & Garrett, 1998). The results from Marans et al. (1991) also demonstrated that cutting times tended to vary depending on which FKB participants wore suggesting that cutting times may vary across different models of FKBs. The results from Dai et al. (2012) suggested that individuals who had ACL reconstruction surgery 6 months prior to returning to sport may be less afraid of landing on their surgical limb while wearing a FKB. The results from Maniar et al. (2019) revealed that the GM muscle is partly responsible for accelerating the body's centre of mass towards the intended direction during cutting maneuvers. More research examining the effects a knee brace has on the kinematics of the movement or task may provide further insight into how a knee brace affects overall performance.

Kinematics

Kinematics describes the sequencing of motion with respect to time (Hall, 2015). Linear and angular kinematic variables commonly include distance, displacement, acceleration, and velocity (Hall, 2015). Most of the research surrounding the effects of knee bracing on lower extremity kinematics has focused on knee joint flexion angles and tibial rotation, as these movements are commonly associated with knee injuries (Anderson, 2017). Research has demonstrated that wearing a FKB reduces the anterior tibial displacement in an ACL deficient knee in a cadaver model during knee flexion and tibial rotation tasks (Beck et al., 1986; Colville et al., 1986; Jonsson & Karrholm, 1990; Mishra et al., 1989; Wojtys et al., 1996) and in research involving human participants (Beynnon et al., 1992; Branch et al., 1988; Decoster & Vailas, 2003; Liu & Mirzayan, 1995). There has been less of a focus on hip and ankle joint angles in the available research.

Kinetics and Kinematics of Jump Landings. Landing from a jump is a physical task that is often required by soccer players when trying to head the ball, and is one of the most common mechanisms of a non-contact knee injury (Boden et al., 2000). Most knee braces are designed to alter lower extremity kinematics and kinetics to reduce the load on the ACL and other ligaments in the knee via increasing knee flexion angle at the point of landing (Boden et al., 2000). Yu et al. (2004) recruited 10 male and 10 female healthy recreational athletes between the ages of 18 to 28 years. Participants were required to wear a specially designed FKB (4titude; DonJoy® Orthopedics, LLC, Vista, California, USA) for the study. Participants performed a stop jump task both with and without the FKB and the knee flexion angle at the point both feet contacted the ground was recorded using high-speed cinematography. Participants wearing FKBs had significantly increased knee flexion angles at the point of landing during a jump (Yu et al., 2004). The researchers also noted that the increased knee flexion angles during landing were not likely the effect of the run-up speed because no significant difference in approach speed between the braced and non-braced conditions was observed (Yu et al., 2004). It was also noted that wearing the FKB did not alter the participants' maximum knee flexion angles (Yu et al., 2004). Despite the FKB not affecting maximum knee flexion angle, it was noted that wearing the brace reduced the load on the ACL and the anterior shear applied to the tibia through the patellar tendon (Yu et al., 2004). Studies have repeatedly shown that anterior shear force applied on the tibia through the patellar tendon is a function of the knee flexion angle and, subsequently, increases strain on the ACL (Boden et al., 2000; Grood et al., 1984; Markolf et al., 1990; Smidt, 1973; van Eijden et al., 1985). Therefore, decreased anterior shear force on the tibia results in an increased flexion angle (Yu et al., 2004). By wearing a FKB, the shear force is decreased as is the risk of an ACL injury (Yu et al., 2004).

Liu et al. (2014) noted similar results, when using a 6061-T6 aluminum FKB (DonJoy® Orthopedics Inc, Vista, California, USA) with an extension constraint hinge mechanism. Extension constraint mechanisms apply increased resistance to the knee joint as the knee approaches full extension and enters hyperextension. This mechanism assists the knee in maintaining some flexion during tasks that may result in a knee injury (e.g., jumping and cutting). Twenty-four healthy recreational athletes who had knee flexion angles of less than 30° at initial foot contact completed the study. Participants were separated into two groups. Group A (n=12) played their sports without wearing the brace from weeks 1 to 4, while from weeks 5 to 8, they wore the FKB. Group B (n=12) played their sports while wearing a knee brace on both legs from weeks 1 to 4 and then played their sports without wearing any knee braces from weeks 5 to 8. In group A, knee flexion angle during both the stop-jump and side cutting tasks increased as participants became more accustomed to the brace (Liu et al., 2014). In group B, after brace discontinuation in week 4, knee flexion angle during both tasks were still greater than their baseline measurements. Participants significantly increased their knee flexion angle at the moment of peak GRF_y. It was reported that the mean knee flexion angle significantly increased in both groups during the stop jump task by the end of week 4 (Liu et al., 2014). Results also showed that the knee flexion angle in group B at the end of week 8 was still greater than the initial measurements at the beginning of week 1 (Liu et al., 2014). The knee flexion angles of the participants in group A did not change between weeks 1 to 4, but the knee flexion angles did increase once the brace was applied. The knee flexion angles of participants in group B decreased in week 8 compared to week 4, suggesting that the retention effects of FKBs after the discontinuation of the brace may not be long-term (Liu et al., 2014). The differences between prophylactic knee braces and FKBs have also been examined during jumping tasks.

Moon et al. (2018) examined the effects of wearing prophylactic knee braces compared to FKBs during a drop box jump. Nineteen male right-leg dominant alpine skiers performed a drop jump from a 40 cm box and a maximum vertical jump under three conditions without a brace, with a FKB, and while wearing a neoprene sleeve prophylactic knee brace. During the drop jump, the maximum knee joint flexion angle for the dominant leg in the non-braced condition was statistically higher than the brace or sleeve conditions (Moon et al., 2018). During the vertical jump, jump height did not differ across all conditions (Moon et al., 2018). These results align with previous literature on healthy athletes under similar conditions (Mortaza et al., 2012; Rishiraj et al., 2011). The application of a knee brace or sleeve resulted in decreased maximum knee flexion angle, while no reduction was observed in knee joint internal rotation angle (Moon et al., 2018). The researchers suggested that the application of a brace and sleeve may not be able to effectively control knee joint rotation, a factor that increases ACL strain. Thus, there is still potential for an ACL injury when wearing either a FKB or sleeve (Markolf, 1995; Weinhandl et al., 2013).

Kinetics and Kinematics of Cutting. The need to perform quick directional changes is an essential component in various sports including soccer (Bompa & Haff, 2009), where rapid-cutting tasks are common (Alentorn-Geli et al., 2009). Cutting maneuvers are often a movement associated with ACL injuries (Grassi et al., 2017; Roth & Oshahr, 2018; Walden et al., 2011; Walden et al., 2015). The effects of knee bracing on the kinetics and kinematics during cutting maneuvers and agility has only started to be investigated in recent years.

Focke et al. (2020) explored the effects of wearing a prophylactic knee brace and a FKB on the kinematics during a 180° pivoting task. Seventeen active ACL deficient individuals approached a fixed force platform at a prescribed speed of 7 km/h. Once participants reached the force platform, they performed the cutting maneuver that involved planting and turning 180° using their injured leg. All participants performed the cutting task under three bracing conditions including no brace, wearing a prophylactic knee brace (SofTec Genu; Bauerfeind Inc., Zeulenroda-Triebes, Germany), and wearing a FKB (4Titude DonJoy®, ORMED GmbH, Freiburg, Germany). Wearing either brace significantly increased knee joint range of motion in the transverse direction compared to the range of motion when not wearing a brace. Previous studies have shown that movements in the transverse direction (e.g., swinging a golf ball or baseball bat) are significantly involved in an ACL injury mechanism (Hughes & Watkins, 2006; Levine et al., 2013). Frontal direction range of motion also decreased significantly using the rigid FKB compared to no brace; however, wearing the prophylactic knee brace revealed no statistically significant reductions compared to no brace condition (Focke et al., 2020). Sagittal direction range of motion also decreased in both braced conditions compared to the non-braced condition. The cutting task was used to rotate the proximal and distal segments of the ACL deficient knee joint and, evaluate the effect of bracing to control motions in the transverse direction but neither brace reduced peak external rotation (Focke et al., 2020). The results from this study may indicate that wearing rigid FKBs may decrease range of motion in the frontal direction. These results may also coincide with some athletes' views on wearing knee braces, as some believe the application of a knee brace may slow the athlete down (Albright et al., 1995; Hewett et al., 2006). Kinetic and kinematic performance differences during reactive agility trials have also been investigated.

Kinetics and Kinematics of Reactive Agility. Reactive agility can be defined as a rapid bodily movement resulting in a change of speed or direction with a change of speed or direction in response to a stimulus (Sheppard & Young, 2006). Similar to cutting maneuvers, reactive agility tasks have also started to gain popularity during assessment and determining return to sport in recent years because they incorporate a decision-making aspect, which is commonly involved across many sports. Zhang et al. (2013) assessed decision time during an agility task. Participants (n=55) stood on a force platform 5 m in front of five lights (one central red light, and four outer green lights). Once the light was illuminated the participant was asked to respond as fast as possible and move to the designated spot of the force platform based on the stimulus location (e.g., left forward, left backward, right forward, or right backward), then returning to the original starting position after the stimulus (Zhang et al., 2013). Results indicated that pre-movement time correlated significantly with reaction time in all four directions (Zhang et al., 2013). These results suggested that the process of perception and decision-making may be more crucial than the neuromuscular component of movement execution in response to an unpredictable stimulus (Zhang et al., 2013).

Wheeler and Sayers (2010) examined kinematic changes during reactive and pre-planned agility-specific tasks and running techniques. Under two conditions, eight professional male rugby players performed a modified Y-shaped agility test. One condition had participants choose the direction to cut towards, while the other condition had participants cut in the opposite direction of an approaching defender. The results showed greater mean lateral movement speed during the run-up phase in the pre-planned condition than in the reactive condition (Wheeler & Sayers, 2010). The increase in lateral movement speed indicated that the movement was directed towards the intended direction sooner. In the change of direction phase, there were no significant differences in mean lateral movement speed between pre-planned and reactive agility conditions (Wheeler & Sayers, 2010). The researchers also measured anteroposterior foot displacement during the two conditions as changes in foot displacement are noticeable during change in direction tasks. The change in displacement represents a crucial element during the change in direction phase of agility manoeuvres (Andrews et al., 1977). The researchers found a significant reduction in anterior foot displacement during the reactive condition compared to the pre-planned condition (Wheeler & Sayers, 2010). Running speed remained the same despite different anterior foot positions between conditions. It was suggested that the relationship between these two components were affected by reactive conditions (Wheeler & Sayers, 2010). The reduction in anterior foot position was related to the unpredictable nature of the reactive agility condition (Wheeler & Sayers, 2010). This study demonstrated that agility execution differed when participants were asked to complete a reactive agility task compared to a pre-planned task. It was reported that the inclusion of a decision-making element seemed to limit lateral movement speed when side cutting was involved but did not affect running speed (Wheeler & Sayers, 2010).

Kinetics and Kinematics of Running. Théoret and Lamontagne (2006) examined the effects of knee bracing (DonJoy® 4titude) on lower extremity kinematics during treadmill running. Participants (n=11) who were ACL deficient performed a 6-minute running trial on a treadmill. Data was collected over a 10 s period during the last minute of the 6-minute run. Participants were separated into two groups depending on the scores obtained from the Knee Outcome Survey Activities of Daily Living Scale and the results of a series of hop tests. The Knee Outcome Survey Activities of Daily Living Scale is a multiple choice subjective questionnaire that measures the individual's perceived knee pain, stiffness, stability, strength, and gait limitations experienced during activity (e.g., during walking). The hop test objectively compared the hop distance during both single and triple hop tests. Participants were placed into the functional group (n=5) if they scored 80% or higher in both the questionnaire and hop test. Those who did not reach the 80% threshold in both tests were placed in the non-functional ACL deficient group (n=6). Participants completed the running trial in both a braced and non-braced condition. The recorded mean running speed in the braced condition was not statistically significant compared to the non-braced condition. There was no statistical significance in mean running speed between the functional and non-functional groups. The lack of significant differences may have been due to the small number of participants in each group which provided lower statistical power. Knee flexion and extension range of motion were nearly identical between the braced and unbraced conditions during the running cycle (Théoret & Lamontagne, 2006). The application of the knee brace significantly reduced internal and external rotational range of motion compared to the non-braced condition during the running cycle (Théoret & Lamontagne, 2006). Participants who were ACL deficient internally rotated during their knee during the late swing phase when not wearing a brace, but this was not observed in the braced condition. By preventing internal rotation during the late swing phase of running, the brace had the effect of placing the knee in a more neutral position in preparation for heel strike. Since most ACL injuries occur during landing and pivoting, this alteration to the joint position is of particular importance for possibly preventing ACL injuries during physical activity (Théoret & Lamontagne, 2006).

Knutzen and colleagues (1987) examined the effects of wearing a knee brace during running. Twenty-one subjects participated in the study and were separated into three groups including a control, an ACL deficient, and an ACL surgically reconstructed group. Participants were fitted for two custom knee braces including the Generation II® FKB and the Marquette knee stabilizer®. Participants completed a 20 m running trial at a pre-prescribed running speed across all conditions. Regardless of which group participants were placed in, both knee braces significantly reduced total knee rotation and the amount of mediolateral movement (Knutzen et al., 1987). Both of the braced conditions also resulted in decreased knee flexion in both the swing and support phases compared to the control condition (Knutzen et al., 1987). The reduction in knee flexion range during both the swing and support phases of running were most likely the primary cause of decreased knee rotation. These results align with previous literature that measured knee joint motion during walking under different bracing conditions (Hannah & Gilles, 1980).

DeVita et al. (1996) examined the effects of wearing a FKB on lower extremity kinematics during a 20 m run. Ten healthy participants (5 males and 5 females) with no history of lower limb injuries volunteered for the study. An Omni™ Scientific OS-5 FKB was used in the braced condition, with the participants completing the run in both the braced and unbraced conditions. While participants ran in the braced condition, there was a 17% greater hip extensor torque reported compared to the unbraced condition (DeVita et al., 1996). This study demonstrated that wearing a FKB allowed healthy individuals to run with greater hip extensor torque when compared to running without a brace (DeVita et al., 1996). Greater hip extensor torque has been associated with, increased workload on the hip, and decreased workload on the knee joint. Adherent tapes are commonly used in sports to help stabilize joints following or to prevent a joint injury, but the affect on gait function during sports has been questioned.

Kinetics and Kinematics of Adherent Tape. To avoid any potential for pain to the knee, taping of the knee joint has also been used and investigated. Kinesio tape® has been regarded as one of the most commonly used adherent tapes on the market (Alrawaili, 2019). Kinesio tape® is a wrapping system created by Kenzo Kase in 1996 and has been assumed to have the capacity to reduce localized swelling, muscle spasms, pain, and sports injuries (Halseth et al., 2004). Studies have shown and reported that the application of Kinesio tape® to the knee may decrease pain, increase muscle strength, and improve gait and function in patients with sports injuries, osteoarthritis, and patellofemoral pain syndrome (Ernst et al., 1999; Hinman et al., 2003). Previous research has also examined the effect of Kinesio tape® in ACL deficient individuals.

A recent study examined the effect of the application of Kinesio tape® in male ACL deficient participants (n=48; Liu et al., 2019). Participants performed an active angle reproduction test, a Modified Star Excursion Balance Test, and a single hop distance test (Liu et al., 2019). The subjective effects of the Kinesio tape® application were measured using the Lysholm scale. The Lysholm scale is a self-report test that measures pain, instability, locking, swelling, gait, stair climbing ability, squatting ability, and the need for support following knee injuries (Liu et al., 2019). The effects on proprioception, balance, functional performance, and anteroposterior shift of the tibia were also measured using an active angle repositioning test, a Modified Star Excursion Balance Test, a single hop distance test, and a KneeLax 3 joint arthrometer, respectively. The results indicated that one day after applying the Kinesio tape® to the knee, there were statistically significant improvements in all measurements compared to baseline (Liu et al., 2019). Similar results were observed on day seven after Kinesio tape® was applied (Liu et al., 2019). The researchers suggested that the application of Kinesio tape® in ACL deficient participants resulted in improved proprioception, balance, and functional performance and that the effects of tape application were maintained for at least seven days (Lieu et al., 2019).

The measurement of neuromuscular contractions in individual muscles is referred to as EMG (Criswell, 2010). With respect to knee braces, past research has examined the effects of EMG activity in the lower extremity muscles, primarily in the hamstring muscle group. The main function of hinged knee braces are to increase stability at the knee joint following an injury; this is done by reducing the anterior shear forces applied to the knee joint (Vailas & Pink, 1993). A reduction in anterior shear forces is achieved by increasing EMG activity in the hamstring muscle group (Kingma et al., 2004), with the long head of the BF muscle offering the greatest reduction in anterior shear forces (Azmi et al., 2018). Therefore, it is important to examine the EMG muscle activity of the BF muscle and other muscles of the lower extremities during regularly performed activities in soccer.

Electromyography

When a skeletal muscle undergoes tension, it produces a stimulus in the form of an electrical voltage (Hall, 2015). The measurement of neuromuscular activity in the human body, which includes the quantity and timing of muscle contractions, is called EMG (Criswell, 2010). A muscular contraction occurs when the protein myosin exerts energy from adenosine triphosphate to create tension in the muscle (Silverthorn, 2014). Electromyography is used to study the neuromuscular responses that muscles produce during certain activities, and this is achieved with the use of electrodes that can measure the electrical voltage produced by the muscle (Criswell, 2010; Hall, 2015). The electrodes can either be surface electrodes or fine wire electrodes. Surface electrodes are placed on the skin's surface above the muscle researchers are trying to measure the muscle activity. On the other hand, fine wire electrodes are inserted into a muscle, leading to a more accurate measurement of muscle activity (Hall, 2015).

Electromyography During Running. As described previously, Théoret and Lamontagne (2006) also examined bracing’s effects on lower extremity EMG activity during a 6-minute running trial in ACL deficient individuals. Mean surface EMG activity was measured in the VL, VM, BF, semitendinosus, and the lateral and medial gastrocnemius muscles during the run. No statistically significant differences were observed in the EMG activity of any lower extremity muscles measured with and without the knee brace during the running trials. While not statistically significant, wearing the brace resulted in increased EMG activity for all of the muscles except for the VL, which had reduced EMG activity (Théoret & Lamontagne, 2006). These results were consistent with previous literature reported by Limbird et al. (1988), where they found decreased EMG activity in the VL muscle and increased EMG activity in the BF muscle during the stance phase of running. The increased EMG activity in the hamstring muscles while wearing a knee brace suggested that bracing an individual with an ACL deficient knee may provide both mechanical and proprioceptive stabilization in the unstable knee joint through the compensatory strategy of using the hamstring muscle to provide dynamic stability in the otherwise hypermobile knee (Théoret & Lamontagne, 2006). Other researchers have also examined the effects of bracing on running performance and mechanics in both ACL reconstructed and ACL deficient individuals.

Electromyography During Cutting and Agility Tasks. Research related to the EMG activity during cutting activities while wearing a knee brace is limited. Branch et al. (1989) recruited 10 participants with an ACL deficient knee. Participants completed a run and sidestep cutting maneuver and planted using their ACL deficient leg during the task. Participants completed the sidestep trials under three conditions including not wearing a brace, wearing a CTi® knee brace (CTi®, innovation Sports, Irvine, CA, USA), and wearing a Lenox Hill® knee brace (Lenox Hill® Hospital Brace Shop, New York, NY, USA). The researchers found that when participants wore the Lenox Hill® brace, the rectus femoris muscle EMG activity increased compared to when not wearing the brace during the swing phase of both the cutting and running activities (Branch et al., 1989). When wearing either brace there was also increased EMG activity reported in the semimembranosus muscle during the swing phase (Branch et al., 1989). The BF muscle had greater peak EMG activity during the swing phase when participants wore the CTi® brace compared to when not wearing a brace, however, this did not occur when participants wore the Lenox Hill® brace (Branch et al., 1989). During the stance phase, wearing either brace resulted in increased quadriceps muscle group and semitendinosus muscle EMG activity when compared to not wearing a brace. There was also increased BF muscle EMG activity during the stance phase when wearing the CTi® brace but no significant increase was recorded for the Lenox Hill® brace (Branch et al., 1989). No significant differences were reported in muscle timing between the braced and unbraced conditions, suggesting that wearing a FKB did not affect proprioception nor the timing or amplitude of muscle activation (Branch et al., 1989). Measuring EMG activity in healthy participants throughout various physical tasks may help researchers understand the movements that cause excessive strain on the ACL.

Husted and colleagues (2016) examined the neuromuscular activity in the BF, semitendinosus, and VL muscles during a one-legged horizontal hop test, a vertical drop jump test, and a side-cutting task. Adolescent female soccer and handball players (n=62) with no musculoskeletal injuries participated in the study. The EMG muscle activity during the side-cutting test was compared to the one-legged hop and vertical drop jump tests. The researchers found a moderate to weak correlation between the side cutting and one-legged hop and vertical drop tests (Husted et al., 2016). A possible explanation for the weak associations in neuromuscular pre-activity between the side cutting and the two other screening tests could have been due to the different nature of the movements in the cutting task compared to the hop and jump tests. These results suggested that the ability to pre-activate the agonistic muscles (e.g., hamstring muscles) during the side-cutting maneuvers were not strongly correlated to other screening tests (Husted et al., 2016). Another possible explanation for the weak correlations between the side cutting and one-legged hop and vertical drop jump tests could have been the highly different nature of the movements between the three tasks as the lower extremity stability may be different for each (Husted et al., 2016). The results from this study suggested that the one-legged hop and drop jump tests do not produce similar neuromuscular hamstring muscle activity patterns during these movements (Husted et al., 2016). Examining the EMG activity during kicking movements relates to one of the most common movements in soccer and may provide insight into how specific muscles behave during this complex movement especially when considering injury patterns that may result in ACL involvement.

Knee Bracing and Soccer Performance

Hinged knee braces help to increase the functional stability of a knee joint following an injury to the knee by reducing anterior shear forces (Vailas & Pink, 1993). One of the main actions to reduce anterior shear forces acting on the knee is to increase EMG activity in the hamstring muscle group (Kingma et al., 2004). Due to the of reduction in anterior shear forces, knee braces are commonly prescribed to athletes returning from an ACL injury (Decoster & Vailas, 2003; McRae et al., 2011). However, research surrounding soccer specific tasks have focused more so on the biomechanical aspects with a limited focus on the effects of EMG activity.

Most research surrounding the effect of knee braces on soccer performance measures has focused on the biomechanical changes when wearing the brace. Tegnar et al. (1988) examined the effects multiple braces had on running time during a figure 8 task. Participants wore four braces, three modified Lenox Hill™ braces, one with lateral supports, one with medial supports, and one with both medial and lateral supports, and an ECKO brace (Orthomedics, Los Angeles, CA, USA). The researchers reported that wearing the knee braces with the medial support and the brace with both medial and lateral supports resulted in decreased running speed. Since the early study by Tegnar et al. (1998), a moderate amount of research has investigated the effects of knee bracing on physiological measures, soccer agility, and kicking. Despite this, the consensus on whether knee braces affect athletic performance is still unclear.

Many researchers have used running as the task to try to understand the physiological effects of knee bracing. Zetterlund and colleagues (1986) discovered differences in energy expenditure during treadmill running. Ten male participants with an ACL deficient knee ran on a treadmill at 161 m/min while wearing a Lenox Hill® brace (Lenox Hill® Hospital Brace Shop, New York, NY, USA) and without a knee brace. Expressed air was collected from the participants for 2-3 minutes and 5-6 minutes in a 350 L Tissot spirometer. The results from the study showed that wearing the FKB resulted in higher energy expenditure than not wearing the brace (Zetterlund et al., 1986). These results are not surprising as previous studies have also shown that wearing a knee brace had similar physiological effects to adding weights to the feet (Hudson & Goemans, 1982; Soule & Goldman, 1969). There was also a significant increase in heart rate when wearing the Lenox Hill® brace compared to no brace (Zetterlund et al., 1986). The increase in heart rate was not surprising, given that heart rate increases linearly with increased levels of exertion (Astrand & Rodahl, 1977). Another study expanded on Zetterlund et al.'s (1986) findings and applied the same tests comparing multiple types of braces at different running speeds. These results may be relevant to athletes participating in running sports, such as soccer because increased energy expenditure can result in the athlete becoming fatigued sooner, requiring them to be substituted sooner or more frequently. This may be a nuisance to the player and coaching staff as the player may not be able to compete at their highest level of performance for an extended time and the coaching staff may have to substitute a player wearing a FKB.

The study by Highgenboten et al. (1991) expanded on the previous study by Zetterlund et al. (1986) examining the effects of wearing four different knee braces while running at three different speeds (6, 7, and 8 mph) on oxygen consumption and heart rate. Fourteen male subjects ranging from 18 to 35 years of age were recruited for the study. Oxygen consumption was recorded at the 3, 4, and 5-minute intervals for each brace condition. The four braces used included the Generation II® Poli-Axial Knee Cage (Generation II® Orthotics Inc, Orange, CA), the Orthotech® Performer (Orthopedic Technology®, Inc, San Leandro, CA), the CTi® Brace (Innovation Sports®, Irvine, CA), and the Lenox Hill® Derotation Brace (Lenox Hill® Hospital Brace Shop, New York, NY, USA). All braces appeared to have a similar effect on oxygen consumption and heart rate with statistically significant differences in physiological responses. Wearing a knee brace, however, did result in significantly higher oxygen consumption rates at higher speeds of running than when not wearing a brace (Highgenboten et al., 1991). As with the previous study by Astrand and Rodahl (1977), Highgenboten et al. (1991) demonstrated that male participants had higher oxygen consumption while wearing multiple models of FKBs. These results may be important to soccer players as rehabilitation and training staff may need to adapt a player's rehabilitation and training program if they choose to wear a FKB when returning to soccer to compensate for the increased energy expenditure. The effect of bracing on agility performance is another vital component of soccer that must be explored.

Agility Performance

Agility is an essential component of most athletic activities. Soccer players routinely perform numerous movements requiring agility, such as cutting and dribbling, all while reacting to stimuli presented to them. Sheppard and Young (2006) proposed a new definition of agility for sports, defined as "a rapid whole-body movement with a change of speed or direction in response to a stimulus" (p. 922). The definition by Sheppard and Young acknowledges the cognitive components of agility (e.g., anticipation and pattern recognition), however, this definition only applies to open skilled agility (e.g., reacting to stimuli with no pre-planned response). This definition also separates agility into two types of movements including change of direction (closed skill agility) and reactive (open skill agility) tasks. Change of direction agility involves a pre-planned task with no stimulus to react to (e.g., T-test), while a reactive agility test involves presenting a stimulus to the participant that they must then react to (e.g., light, sound, or a live tester; Altman et al., 2020; Sheppard & Young, 2006). Other researchers have suggested that agility tests should be crucial physical performance indicators and should be a part of standard physiological testing for soccer players (Svensson & Drust, 2005).

The Y-shaped agility test for invasion sports (e.g., team sports that involve invading the opponent's territory, such as rugby, basketball, and soccer) was developed by Sheppard et al. (2006). This test required participants to run straight forward and perform a cut at a 45° angle in the opposite direction the tester ran towards. The total time to complete the test is recorded to indicate the reactive agility capabilities of the participants (Altman et al., 2020). It has been reported that this test has demonstrated high intraclass correlation and reliability (Sheppard et al., 2006). Researchers have investigated the effect of knee braces on agility performance using this test or variations of this test.

Knee Bracing and Agility Performance. Many researchers have also provided evidence that wearing a FKB in non-injured athletes does not hinder athletic performance (Greene et al., 2000; Rishiraj et al., 2000; Rishiraj et al., 2009a; Rishiraj et al., 2009b). Despite the purported benefits of using a FKB, anecdotal feedback has reported that knee bracing is uncomfortable and impedes athletic performance, especially with field-based sports (Griffen et al., 2006; Hewett et al., 2006).

Rishiraj and colleagues (2011) examined the impact of wearing a FKB on agility, acceleration, power, and speed in 27 male athletes who wore a custom fitted Extreme Ligament Knee Brace (Össur Orthopedics, Richmond, Canada). Participants wore the FKB during their 20-minute warm-up to get accustomed to the brace before completing 10 trials (5 braced and 5 non-braced) of an agility T-test, a 2 m sprint test, and a vertical jump test. To evaluate the potential adaptation to the FKB, participants performed these tests twice per day for a total of 2 days in each bracing condition (14 hours in each condition). Mean sprint test time between the two bracing conditions was identical but these results were not surprising given the short sprint distance of only 2 m. After wearing the FKB for a total of 14 hours, the time to complete the agility T-test was not significant at the end of the last braced session compared to the initial braced session (Rishiraj et al., 2011). The results between braced and non-braced in the initial braced conditions were statistically significant in the first session but diminished over time as athletes became more accustomed to using the brace. The results between braced and non-braced conditions in the initial sessions may be attributed to the proprioceptive effects of wearing a FKB (Rishiraj et al., 2011). Previous research has illustrated that alterations in proprioceptive feedback (in ACL deficient, ACL reconstructed, and non-injured individuals) due to bracing may be partly responsible for performance changes and improvements in speed and agility over time (Birmingham et al., 1998; Herrington et al., 2005; Ramsey et al., 2003; Reed-Jones & Vallis, 2007). Other researchers have also examined the effects of bracing on kinematic measurements while completing different agility tests.

Bodendorfer et al. (2019) explored the effects of wearing a commercially available neoprene knee sleeve (Breg® Neoprene Knee Support, Breg®, Inc., Carlsbad, CA, USA) compared to a custom fitted prophylactic knee brace (Breg® Roadrunner™ Hinged Knee Brace, Breg®, Inc., Carlsbad, CA) on their dominant leg on the kinematics while completing a 90° cutting task. Ten recreational athletes (5 males and 5 females) performed a forward sprint followed by a 90° pivot on the dominant foot and then a continued sprint in that direction. All participants performed the cutting task under three conditions, including without a brace or sleeve, while wearing a knee sleeve, and while wearing a hinged prophylactic knee brace. During the cutting agility test, no statistically significant differences were found when using either the knee sleeve or hinged prophylactic knee brace compared to the non-braced condition (Bodendorfer et al., 2019). These results showed that athletes can use both knee sleeves and prophylactic knee braces without experiencing negative effects on their time to complete an agility test.

Greene et al. (2000) examined the effects of wearing a prophylactic knee brace on 30 college football players completing a 40-yard dash and a four-cone agility test. Participants completed both tests wearing six different off the shelf prophylactic knee braces. During the 40-yard dash, every brace condition resulted in faster times than the non-braced condition, except when participants wore the OMNI-AKS™ 101W (OMNI Life Science™, Springville, Utah, USA). During the four-cone agility test, participants had faster times when wearing the Air Armor 2 Knee and Thigh Protection System (Air Armor, Inc., Scottsdale, Arizona, USA) and the OMNI™ brace compared to all other braced conditions, and also had similar times to the non-braced condition (Greene et al., 2000). Most participants reported that they preferred the Air Armor 1 Knee and Thigh Protection System (Air Armor, Inc., Scottsdale, Arizona) and the

McDavid knee guard (McDavid, Clarendon Hills, Illinois, USA) when asked on the subjective questionnaire (Greene et al., 2000). When participants were asked which brace they believed to offer the most protection, most participants selected the Breg Tradition (Breg, Inc., Vista, California, USA). In trials in which participants wore the Breg knee brace, the times to complete the 40-yard dash and four cone agility times were the slowest (Greene et al., 2000). These results suggest that the brace that does not affect athletic performance (e.g., faster time to complete agility test) may not align with the brace that participants believe offers the most protection.

Purpose of Research

Wearing a knee brace has been reported to be effective in reducing tibial rotation, which is one of the primary movements resulting in a knee injury (Anderson, 2017). The effects of bracing on different performance measures have produced mixed results. A study by Rishiraj et al. (2011) demonstrated no change in agility or cutting task time, Tegnar et al. (1988) reported decreased running time during a figure 8 task, while Greene et al. (2000) reported that wearing certain knee brace models (e.g., Air Armor 2 Knee and Thigh Protection System and the OMNI™ AKS™ 101W knee brace) resulted in faster agility test times. Reactive agility is a variable of interest that has been researched more recently but has not been explored in the context of wearing a knee brace in soccer athletes. Most field sports, such as soccer, do not have pre-planned movements, and, therefore, performance tests measuring agility in field-based athletes should incorporate a reactive component to simulate sport specific tasks.

Since knee braces represent the most common method of injury prevention used (Yeung et al., 2011), soccer athletes and healthcare professionals must be aware of the possible effects of wearing a knee brace on reactive agility, and EMG activity on the lower extremity muscles, as these effects have not been clearly investigated in previous literature. These factors may benefit soccer athletes and healthcare professionals as they will then be aware of the potential benefits or impediments associated with wearing a knee brace during soccer specific tasks. The three muscles chosen are of particular importance as the GM muscle is activated during cutting maneuvers. The BF muscle is the most commonly activated muscle during running tasks when a knee brace is applied, but there is limited research on the effects of the BF muscle during reactive cutting maneuvers when a knee brace is applied. The VL muscle was chosen as it is the most commonly injured quadriceps muscles during soccer activities.

There has been a limited amount of research examining the effect of knee bracing on lower extremity muscle activity during reactive agility performance in a soccer population. This pilot study was designed to fill this gap in the literature and determine if performance differences existed between healthy soccer players wearing a brace compared to their performance when not wearing a knee brace. Therefore, the purpose of this pilot study was to examine differences between braced and non-braced soccer players on measures of reactive agility time (s), and EMG activity (% MVC) of the GM, BF, and VL during the acceleration and change of direction phases of the Y-shaped reactive agility test.

Research Questions

The following questions were used to guide this pilot study:

1. Is there a difference between the knee brace conditions (braced versus non-braced) for measures of reactive agility time (s) during a Y-shaped reactive agility test?
2. Is there an interaction effect between the knee brace conditions (braced versus non-braced), muscle type (GM, BF, and VL muscles), and phase (acceleration and cutting) for measures of lower extremity EMG muscle activity (%MVC) during a Y-shaped reactive agility test?

Chapter Two: Methodology

Participant Inclusion and Exclusion Criteria

Prospective participants for this pilot study were included if they were: 1) male or female; 2) were between the ages of 18-29 years of age; 3) physically active individuals who participated in at least 150-minutes of moderate-to-vigorous aerobic activity each week; and 4) were experienced soccer players who played on an organized team with at least one game or practice per week within the past 5 years.

Participants were excluded from the pilot study if they: 1) suffered from a diagnosed or self-reported lumbar spine or lower limb injury that impeded their ability to perform running, cutting, or kicking tasks (e.g., sprain, fracture, tendinitis, or tendinosis); 2) had undergone any lumbar spine or lower extremity surgical procedures within the last year; 3) had not been cleared by their physician to return to physical activity involving sprinting, cutting, or kicking maneuvers; and 4) were allergic or sensitive to adhesive tape or any of the materials present in the electrode sensors or the prophylactic knee brace (e.g., neoprene, elastane, cellulose, or synthetic rubber).

Research Recruitment Procedures

Potential participants were recruited via purposive and convenience sampling. The target population was soccer players with no underlying lower limb injuries. The student researcher recruited 24 participants. A sample size of 32 participants was calculated based on a priori power of analysis for a repeated measures 2x2x3 ANOVA with an effect size of .14 (η^2) based on a standardized large effect size for eta squared and a power of rejection of 80% at α=.05 (two-tailed) in the Y-shaped reactive agility test performance measure. Participants were recruited using recruitment posters containing an overview of the pilot study and the student researcher's contact information (see Appendix A). These posters were hung around Lakehead University and the Sanders Building, in visible, high-traffic areas throughout the buildings. Recruitment posters were also posted on various social media platforms on the student researcher's and Lakehead University's School of Kinesiology social media accounts (e.g., Instagram, Facebook, Twitter, and Snapchat). The posters included the title of the pilot study, what was required of the participants, the names of the student researcher and supervisor of the pilot study, and relevant contact information. Participants were also contacted via word-of-mouth, where he/she was encouraged to contact the student researcher if he/she were interested in participating in the pilot study. The student researcher also contacted local soccer coaches and organization officials seeking permission to invite their players to participate in the pilot study. Once a potential participant expressed interest in partaking in the pilot study, he/she was given an information letter (see Appendix B) for his/her perusal. The student researcher also answered any of the participant's questions about the pilot study. Once the potential participants were willing to participate in the pilot study after reading the provided documents, the student researcher set up a testing session with the participant at a mutually agreeable time.

Screening Measures

Physical Activity Readiness Questionnaire.

The PAR-Q+ is a pre-screening tool developed by the Canadian Society for Exercise Physiology (CSEP) to identify any medical conditions that may make physical activity unsafe for an individual (CSEP, 2013). Participants completed the PAR-Q+ form prior to participating in any of the physical components of this pilot study. If a participant answered yes to any of the questions on the PAR-Q+ form, he/she were deemed ineligible to participate in the pilot study and were encouraged to consult with his/her health care provider.

Instrumentation

Electromyography.

Surface EMG electrodes were used as a non-invasive procedure to measure the neuromuscular activity (Konrad, 2005). Surface EMG has demonstrated high reliability when measuring the BF, GM, and VL muscles during dynamic tasks (Fauth et al., 2010; Muyor et al., 2020) and good-to-excellent intra-session and inter-trial reliability (Charlton et al., 2017). The Delsys Trigno™ Wireless EMG system and Trigno™ IM sensors were used for this pilot study. The Delsys Trigno™ EMG system and accompanying sensors can collect 16 EMG channels simultaneously, with a transmitting range of 20 m (Delsys Inc., 2012). For this pilot study, the Delsys Trigno™ Wireless EMG system was wirelessly connected with the LabChart® 8 computer application via the Delsys Trigno™ Control Utility computer application. The LabChart® 8 software then recorded the EMG activity of the BF, VL, and GM muscles, measured in millivolts (mV) throughout data collection.

LabChart® 8 Software.

For this pilot study, the EMG data was collected and displayed in real-time by the LabChart® 8 software. A total of six channels were used, three channels were used to collect the EMG data from the BF, VL, and GM muscles using the Delsys Trigno™ Wireless EMG system, three channels were used to distinguish the change in direction of the Y-shaped reactive agility test using a Delsys' magnetometer sensor. The LabChart® 8 software was used to rectify, filter, and extract all EMG data. The raw EMG data was bandpass filtered with a low pass frequency of

500 Hz and a high pass frequency of 6 Hz. These values were determined via a spectral analysis. The data was full wave rectified following the bandpass filtering to create a linear envelope. The peak EMG data was reported based on the rectified, filtered, and sampled data. All EMG data was sampled at 1000 samples per second.

Brower© Timing Gates.

Brower© infrared timing gates were used to create the start and finish lines for the agility test to measure agility test time. The timing gates created a starting line using an infrared signal connecting multiple sensors. When the participant crossed the first infrared sensor, the timer started. When the participant crossed the second infrared sensor, the time between infrared distributions was recorded as the agility test time. Timing gates have been shown to have high intra trial reliability, with a coefficient variation of .69 to 1.2% when measuring 10 m sprint speed (Cronin & Templeton, 2008).

Agility Test.

For the purposes of this pilot study, a Y-shaped reactive agility test was used to assess the participant's reactive agility performance (see Appendix E). The agility test chosen for this pilot study was adapted from Sheppard et al. (2006) because the agility test simulates movements witnessed in soccer, such as running and cutting while reacting to a human stimulus. This test demonstrated good interclass reliability (.87-.99) and interclass correlation (.82-.83) when measuring agility time (Altman et al., 2020; Pojskic et al., 2018). For the purposes of this pilot study, the time to complete the test was recorded in s.

Procedures

After obtaining ethical approval from the Lakehead University Research Ethics Board, one testing session was required to collect the data for each participant and each session lasted approximately 45-60 minutes. The collection of background data took place in room SB-1025 in the Sanders Building at Lakehead University. The student researcher first provided an overview of the pilot study and completed the informed consent process with the participant, answering any questions the participant had. If the participant chose to partake in the study, they were asked to sign the informed consent form and completed the PAR-Q+ form. Once completed, background information was recorded, including the age (years), sex, height (cm), mass (kg), and the soccer experience (years) of the participant.

After collecting the background data, the participant was randomly assigned to one of two groups where they completed their first trial. The participant was randomly assigned using a random number generator between one and two, where one indicated the participant was assigned to the non-braced condition first, and two indicated the participant was assigned to the knee brace condition first (DonJoy® Playmaker II). Participants were appropriately sized for the correct knee brace using the circumference measurements provided on the company website and supporting documents provided with the knee brace. The student researcher asked the participant to stand with their legs shoulder width apart and slightly flexed. The student researcher then measured the upper leg circumference (15 cm above the knee centre) and the lower leg circumference (15 cm below the knee centre) before measuring the knee joint circumference. Based on the measurements recorded, the participant was assigned the appropriately sized brace that aligned with the company's recommended circumference measurements.

The student researcher then applied three wireless surface electrodes from the Delsys Trigno™ Wireless EMG system to the skin of the participant's dominant leg, defined as the leg the participant uses to kick a ball. Before applying the electrodes, the participant was asked for consent to place the electrodes on their skin. After obtaining verbal consent, the student researcher prepared the skin by cleaning the area with isopropyl alcohol and shaving the area of excessive hair, if necessary. The alcohol and shaving removed any dry skin and hair that may have affected electrode adherence and signal attenuation (Delsys Inc., 2012). Adhesive tape was applied overtop the electrode to ensure clothing or the knee brace did not loosen the electrode from the skin. Following the application of each electrode, a maximal voluntary contraction (MVC) was performed for each corresponding muscle, based on the SENIAM guidelines. Electrode application and MVC were performed systematically, beginning with the GM, BF, and finally, the VL muscles.

The first electrode was applied to the GM muscle (see Figure 5). To landmark the position for electrode placement, the participant was positioned in side lying on a flat surface with their dominant knee slightly flexed. The electrode was placed 50% of the distance from the highest point on the iliac crest to the greater trochanter (SENIAM, 2014). The participant was then asked to complete a MVC for the GM muscle; in a side lying position, the participant abducted the hip 25° while the student researcher provided manual resistance for 3 s and the EMG activity was recorded (SENIAM, 2014).

Figure 5.

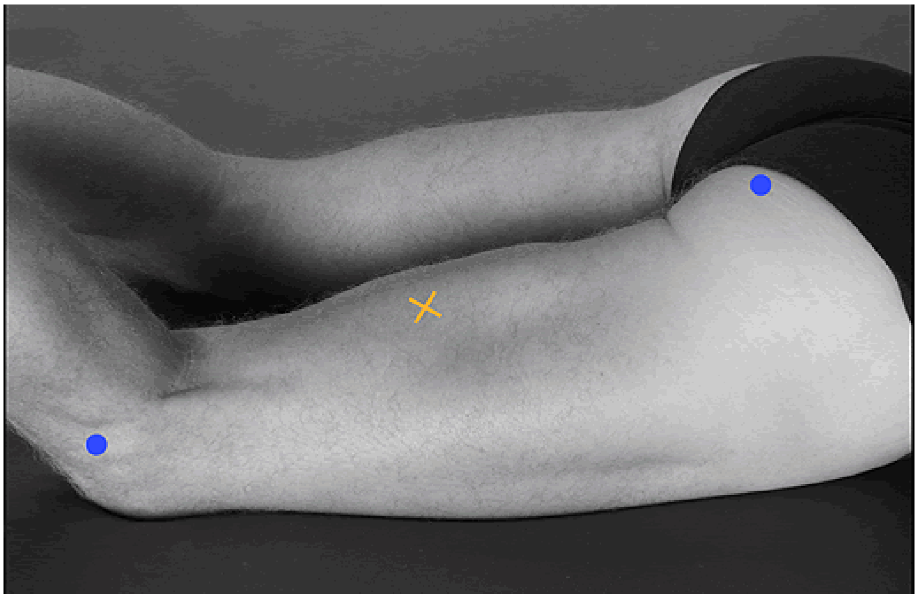
Electrode location one.

Note. This figure displays the location for the GM muscle. The blue dots represent anatomical landmarks. The yellow X represents the electrode location. Retrieved from http://seniam.org/gluteusmedius.html

The second electrode was applied to the BF muscle (see Figure 6). To landmark the position for electrode placement, the participant was positioned lying prone, with the dominant knee in a flexed position that was less than 90° and in minimal lateral rotation. The electrode was placed 50% of the distance from the ischial tuberosity to the lateral epicondyle of the tibia (SENIAM, 2014). The participant was then asked to complete a MVC for the BF muscle while lying in a prone position with the hip in slight lateral rotation. The participant was asked to flex the knee (from 60°) while the student researcher provided manual resistance for 3 s and the EMG activity was recorded (Halaki & Ginn, 2012; Hsu et al., 2009).

Figure 6.

Electrode location two.

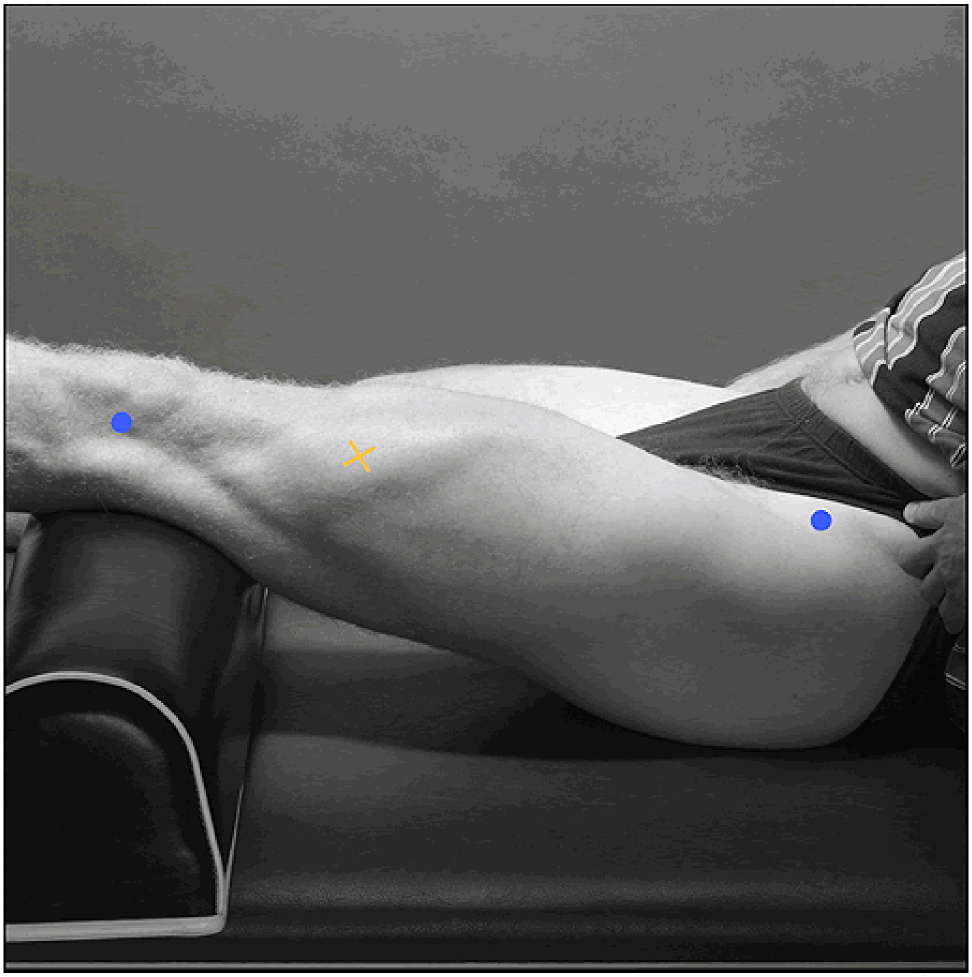


Note. This figure displays the location for the BF muscle. The blue dots represent anatomical landmarks. The yellow X represents the electrode location. Retrieved from http://seniam.org/bicepsfemoris.html

The final electrode was applied to the VL muscle (see Figure 7). To landmark the position for electrode placement, the participant was positioned lying supine on a table with the knee in slight flexion. The electrode was placed at two-thirds of the distance from the anterior superior iliac spine to the lateral portion of the patella (SENIAM, 2014). The participant was asked to again complete a MVC for the VL muscle. While the knee was positioned in slight flexion, the participant was asked to extend the knee while the student researcher provided manual resistance for 3 s and the EMG activity was recorded (Halaki & Ginn, 2012; Hsu et al., 2009).

Figure 7.

Electrode location three.



Note. This figure displays the location where the electrode placed on the VL muscle. The blue dots represent anatomical landmarks. The yellow X represents the electrode location. Retrieved from http://seniam.org/quadricepsfemorisvastuslateralis.html

After recording the EMG activity for the MVCs, the participant applied the knee brace (if assigned to the brace group first). The participant applied the appropriately sized knee brace based on the circumference measurements the student researcher recorded previously. The student researcher supervised the application of the knee brace to ensure the brace was applied correctly. The participant was allowed to adjust the knee brace during the testing session, if required, to maintain the manufacturer's described fit. At that time, the student researcher also applied a fourth electrode. This electrode used the magnetometer function and was used for determining the directional change of the participant during the Y-shaped reactive agility test. This electrode was placed below the participants umbilicus to prevent motion of the limbs from interfering with the magnetometer (see Figure 8).

Figure 8.

Electrode location four

Note. This figure displays the location where the fourth electrode was placed. The yellow dot represents the position just below the umbilicus. Retrieved from White & Folkens, 2005.

The next portion of data collection took place on the indoor turf in the Lakehead University Hangar. Following the application of the knee brace (if necessary), the participant completed a standardized 5-minute warm-up, which included jogging, short accelerations, and movement preparation exercises at an intensity of 10-12 on the Borg Scale of Perceived Exertion

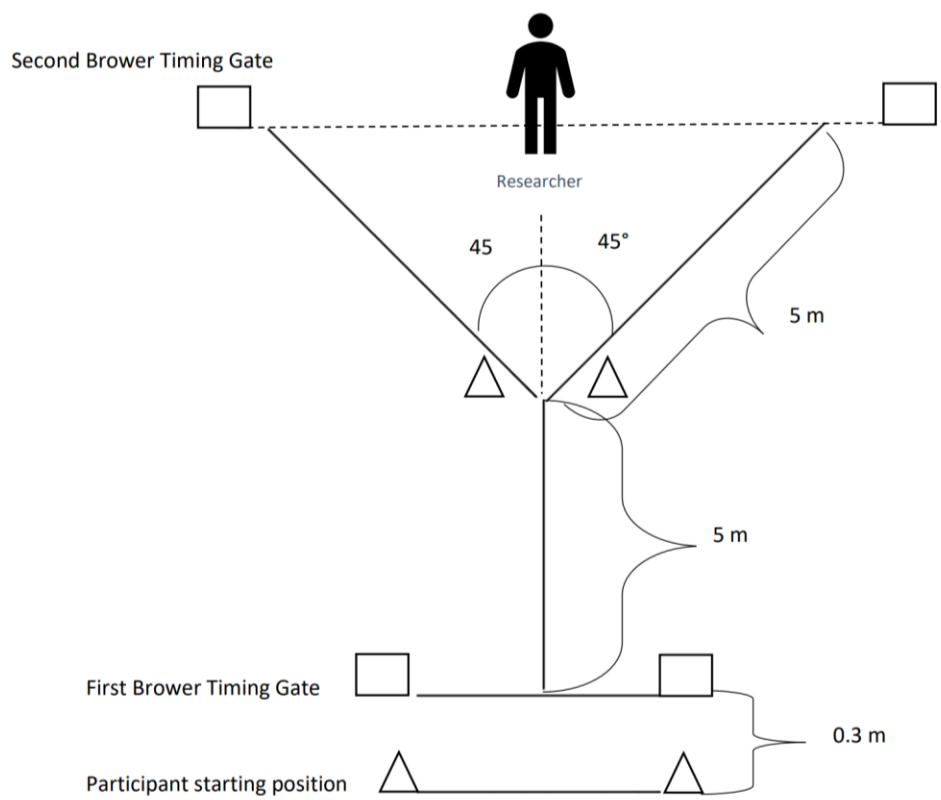
(CSEP, 2013) supervised by the student researcher. A visual representation of the Borg Scale was shown to the participant to help them determine the appropriate intensity (see Appendix G). Subsequently, the participant completed two familiarization trials of the agility test (see Figure 9).

Following the standardized warm-up, the student researcher informed the participant about the Y-shaped reactive agility test via a verbal explanation and provided a visual demonstration. To perform the reactive agility trial, the participant was positioned on a starting line 0.3 m behind the first Brower© timing gates. The participant initiated the test by accelerating forward from the first set of cones at the starting line. After passing the first timing gate, the participant then sprinted for 5 m from the first Brower© timing gate to the second set of cones, where the student researcher visually indicated using hand signals and verbally indicated which direction the participant cut towards (left or right). To ensure consistency when the participants made the directional change to either direction, a visual cue in the form of a set of cones was placed at the 5 m mark. When a participant reached the second set of cones, the student researcher then visually (e.g., by lifting the arm of student researcher on the side the participant cut towards) and verbally indicated the direction the participant had to cut towards. The participant then reacted to the direction the student researcher gave and cut at a 45° angle in that direction. The participant then sprinted for 5 m and crossed the last Brower© timing gate, where their time was recorded in s.

The participant was allowed to perform a maximum of two familiarization trials to become accustomed to the test, to ensure the equipment was working properly, and to allow the student researcher to provide feedback and make any necessary corrections or modifications. Once the participant was familiar with the testing procedure, they were asked to perform four recorded trials cutting twice to either direction. The order participants cycled through the agility test was dependant on the participant number they were assigned. If the participant was assigned an odd number, they cut towards the left first trial, followed by cutting to the right on their second trial, then to the left again on their third trial, and to the right again on their fourth trial. If participants were assigned an even number, they cycled through the agility test in the opposite order. Participants were not told which participant number they had been assigned. This was to ensure the agility test had a reactive component when completing the Y-shaped reactive agility test. The student researcher began collecting the EMG data and notified the participant to start the maximal reactive agility trial when they were ready. The EMG data was collected in two phases. Phase one, the acceleration phase, was defined from the starting position to the moment the participant initiated the directional change. Phase two, the change of direction phase, was defined from the moment they initiated the change in direction to the end of the agility test. The magnetometer feature in the Delsys Trigno® Wireless EMG sensors were used to determine the moment the participant initiated the directional change (see Figure 10). Three comments were also inserted into the LabChart® 8 data file. The first comment was placed when the participant started the Y-shaped reactive agility test, the second comment was placed when the participant initiated the directional change, and the third comment was placed when they passed the second pair of Brower© timing gates. A directional change was defined as a noticeable change in the magnetic field (Tesla) in the y and z directions of the magnetometer measurements in the LabChart® 8 software (see Figure 10). A trial was deemed successful once the trial was without any errors from both the participant (e.g., tripping, falling, or injury) and the student researcher (e.g., Brower© timing gates recorded trial time and EMG sensors recorded EMG activity). Once the student researcher deemed the trial satisfactory, the time and EMG data was recorded. The participant was then asked to perform two more successful trials but, was given a 1-minute break in between trials where the participant adjusted the brace, if necessary. For each reactive agility trial, EMG muscle activity was separated within the two phases, this was used to determine which values in EMG muscle activity were analysed to find the peak EMG value for each muscle in each phase. This was adapted from previous research that investigated peak EMG as the primary measure of muscle activity (Castro et al., 2013; Gribble et al., 2006; Jeffriess et al., 2015; Lockie et al., 2014).

Figure 9.

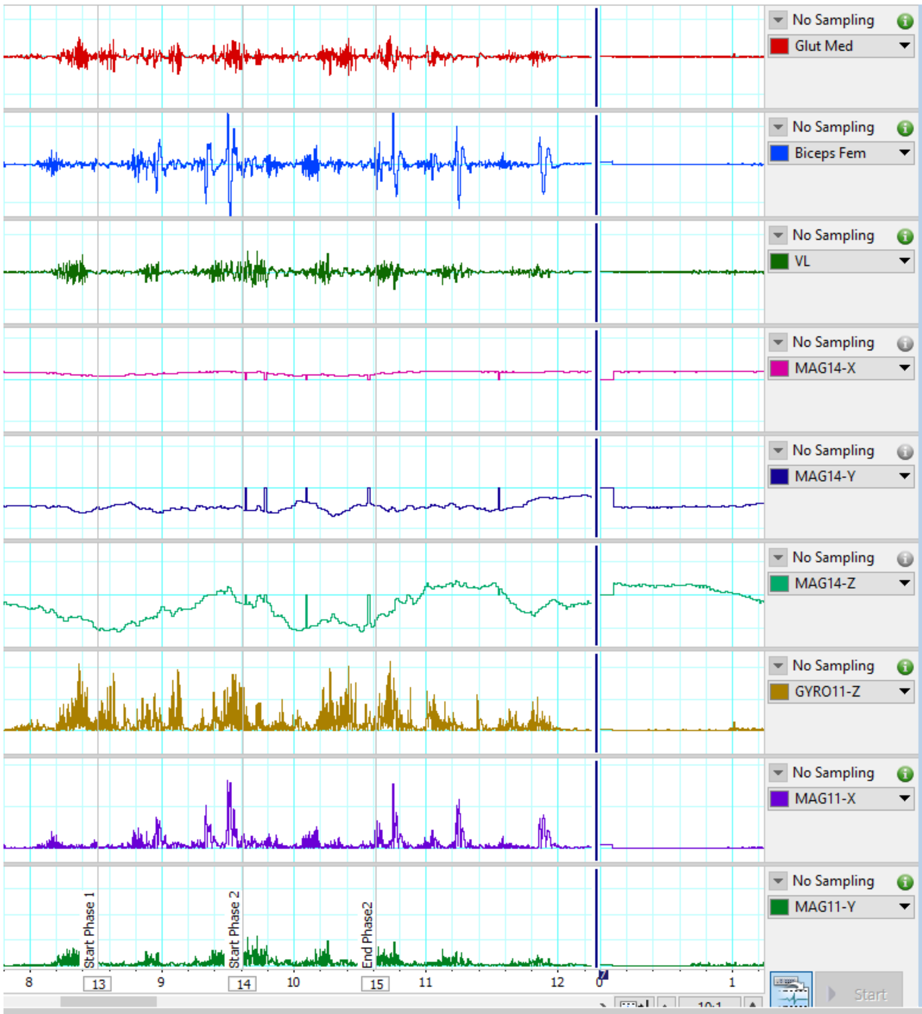
Y-shaped reactive agility test diagram.



Note. This figure displays a diagram of the Y-shaped reactive agility test.

Figure 10.

LabChart® 8 data file of Y-shaped reactive agility test.



Note. This image displays a sample of participant EMG and magnetometer data.

After completing the reactive agility trial under the first condition, a 5-minute rest period was provided. The purpose of this rest period was to allow the participant to transition to the next component of the testing protocol and allow for physical recovery. If the application of a knee brace was required, the participant then applied the knee brace at that time as described previously. When the participant transitioned to the following testing condition, the testing procedures mirrored the first condition, as described in detail previously. After completing the task under both bracing conditions, the participant removed the knee brace (if necessary) and electrodes. Once the brace and electrodes were removed, the participant completed a 5-minute cooldown supervised by the student researcher consisting of jogging with an exertion level of 10-12 on the Borg scale. The Borg scale acted as a visual aid to the participant to help them attain the desired intensity. The testing session was concluded after the participant completed the 5-minute cooldown, and the participant was thanked for their involvement.

Preliminary Data Analysis

Electromyography Data

Peak EMG activity (mV) for the 3 s MVC was first calculated. Peak EMG activity (mV) for each muscle during the two phases of the fastest trial reactive agility trial was checked for reliability using a two-way, mixed effects intraclass correlation within the IBM® SPSS® 28 statistics software computer application. This was done to ensure no outliers were present. If outliers were present in the fastest trial, the data for the next fastest trial was checked for reliability and used if no outliers where contained. The peak EMG data of the fastest of the four trials for each condition and phase was then be expressed as a percentage of MVC (%MVC).

Performance Data

Reactive agility time (s) of the fastest trial from each bracing condition for each participant was checked for reliability to ensure no outliers were present, using a two-way, mixed effects intraclass correlation within IBM® SPSS® 28 statistics software. A two-way, mixed-effects model was used because the student researcher acted as the single rater across all trials for all participants (Koo & Li, 2016).

Statistical Analysis

The independent variable of brace condition consisted of two levels, including the no brace control and brace intervention. The independent variable phase for the Y-shaped reactive agility test consisted of two levels, including the acceleration phase and the change of direction phase. The independent variable muscle type consisted of three levels, including the GM, VL, and BF muscles. The dependent variables for the Y-shaped reactive agility test included the fastest reactive agility trial time and the peak EMG activity. The dependant variable for the VL, BF, and GM muscles and brace condition included EMG. For all the variables, a box and whisker plot were visually inspected to determine the presence of outliers. All analyses were performed with and without the outliers to determine if they influenced the results, if they were present. The data was then be checked for normality using the Shapiro-Wilk test for normality.

Following the preliminary analysis, the data was transferred into an IBM® SPSS® 28 data file for further analysis. A paired samples t-test was conducted for research question one to compare the type of brace condition on measures of reactive agility time. For research question two, a three-way ANOVA with repeated measures on all factors was conducted to examine the interaction effect of brace condition (braced or non-braced), muscle type (VL, BF, or GM muscles), and phase (acceleration or change of direction phase) for measures of EMG at $p<.05$. If an interaction effect was found, the student researcher explained the interaction using two-way ANOVAs. If no interaction effect was found, the student researcher examined the main effects of brace condition, agility phase, and muscle type separately. In addition, the researcher examined any two-way interactions that manifested in the analysis.

Chapter Three: Results

The purpose of this pilot study was to examine differences between braced and non-braced soccer players on measures of reactive agility time (s), and EMG activity (% MVC) of the GM, BF, and VL during the acceleration and change of direction phases of the Y-shaped reactive agility test.

Demographics

A total of 24 participants competed the pilot study. Demographic information of all participants is presented in Table 1.

Table 1.

Participant demographic information

Sex	14 male, 10 female
Height (cm)	174.83 +/- 9.92
Mass (kg)	77.20 +/- 11.21
Age (years)	23.08 +/- 2.76
Experience	11 recreational, 9 varsity, 3 collegiate, 1 semi-professional

Question One: Is there a difference between the knee brace conditions (braced versus non-braced) for measures of reactive agility time (s) during a Y-shaped agility test?

Descriptive Statistics

The mean agility time (s) and standard deviation for the no brace condition and the DonJoy® Playmaker II condition are depicted in Table 2.

Table 2

Mean agility time

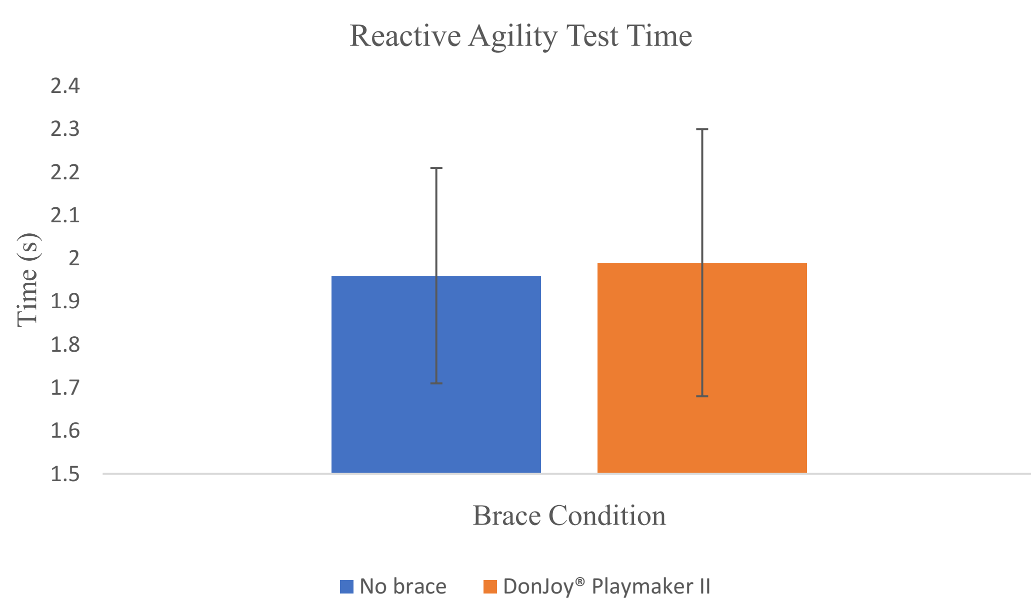
Dependant Variable	No Brace			DonJoy® Playmaker II		
	Mean	SD	n	Mean	SD	n
Agility Time (s)	1.96	.25	24	1.99	.31	24

Inferential Statistics

A paired samples t-test was conducted to compare the effect of the independent variable (knee brace condition) on Y-shaped reactive agility test time. There was no statistically significant difference in Y-shaped reactive agility test time between the no brace condition and knee brace condition, *t*(23)=-1.149, *p*=.262 (two-tailed), *d*=.235, 95% CI[-638, .174]. See Figure 11 for an illustration of these findings.

Figure 11.

Y-shaped reactive agility test Time Results.



Note. This graph displays the mean and standard deviations of Y-shaped reactive agility test time for both the non-braced and braced (DonJoy® Playmaker II) condition

Question Two: Is there an interaction effect between the knee brace conditions (braced versus non-braced), muscle type (GM, BF, and VL muscles), and phase (acceleration and cutting) for measures of lower extremity EMG muscle activity during a Y-shaped agility test?

Descriptive Statistics

The mean EMG activity (%MVC) for each of the three lower extremity muscles are presented for the no brace condition and the DonJoy® Playmaker II condition in both the acceleration and change of direction phases. These results are depicted in Table 3.

Table 3.

Electromyography and descriptive statistics for muscle activity of participants for the Y-shaped reactive agility test.

Dependant Variable	**No Brace**		**DonJoy® Playmaker II**	
EMG (%MVC)	Mean	SD	Mean	SD
GM Mean EMG Acceleration Phase	76.18	52.26	83.76	62.09
BF Mean EMG Acceleration Phase	77.25	32.89	82.99	53.76
VL Mean EMG Acceleration Phase	124.23	103.22	87.72	75.33
GM Mean EMG Change of Direction Phase	121.78	104.41	114.95	98.42

BF Mean EMG Change of Direction Phase	99.39	45.05	87.90	38.95
VL Mean EMG Change of Direction Phase	122.22	104.41	93.80	79.82

Note. Descriptive statistics are presented in Table 3.

Inferential Statistics

Three-way ANOVA. Before conducting the three-way analysis of variance, a boxplot inspection was performed on the data. Four outliers were identified in the no brace condition and five outliers in the braced condition. The researcher decided to conduct the analysis with and without outliers and found that the outliers influenced the statistical significance of the results; thus, the EMG data of the agility test was replaced with the participant's second fastest trial data that did not contain outliers. Next the homogeneity of the data for the repeated measures was examined and no violations on the assumption of sphericity were found, as assessed by Mauchly's Test of Sphericity (p=.126). The completion of the three-way repeated measures ANOVA revealed no statistically significant interaction effect between the three independent variables (brace condition, phase, and muscle type) on peak EMG activity (%MVC) during the Y-shaped reactive agility test, $F(2,46)=2.296$, $p=.124, \eta^2=.173$. There was no statistically significant difference for measures of muscle type, phase, and brace condition on EMG activity (%MVC) during the Y-shaped agility test. Next the researcher examined any possible two-way interactions between muscle type, phase, and brace conditions on measures of EMG activity (%MVC) during the Y shaped agility test.

Two-Way ANOVA – Phase and Muscle Type. Before conducting the two-way ANOVA, the homogeneity of the data for the repeated measures was examined and no violations on the assumption of sphericity were found, as assessed by the Mauchly's Test of Sphericity (p=.453). The two-way ANOVA revealed a statistically significant interaction in peak EMG activity between phase and muscle type during the Y-shaped reactive agility test with a large effect size, $F(2,22)=6.565$, $p=.006$, $\eta^2=.374$ as shown in Figure 13. To help explain the interaction, paired sample t-tests were conducted to examine differences between the two phases (acceleration and change of direction) for each of the three muscle types (GM, BF, and VL) respectively on EMG measures.

The first paired samples t-test compared the difference in peak EMG activity in the GM muscle on the two phases. The paired samples t-test revealed a statistically significant increase in the peak EMG activity in the GM muscle between the acceleration phase 79.97+/-10.64 %MVC and the change of direction phase 118.36+/-16.27 %MVC with a small effect size, $t(47)=-3.165$, $p=.003$, $d=.457$. See Figure 12 for an illustration of these findings.

The second paired samples t-test compared the differences in peak EMG activity of the BF muscle during the acceleration phase and the change of direction phase. The paired samples t-test revealed a statistically significant increase in the peak EMG activity in the BF muscle between the acceleration phase 80.12+/-44.18 %MVC and the change of direction phase 93.65+/-42.07 %MVC with a small effect size, $t(47)=-2.284$, $p=.027$, $d=.330$. See Figure 12 for an illustration of these findings.

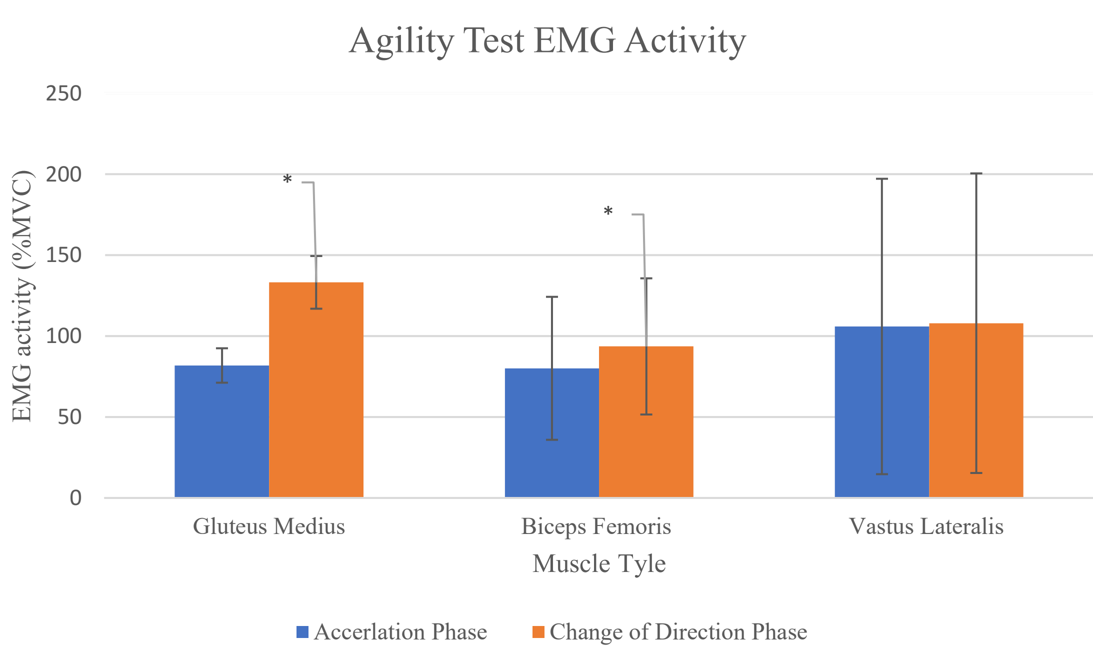
The third paired samples t-test compared the differences in peak EMG activity of the VL muscle during the acceleration phase and the change of direction phase. The paired samples t-test revealed no statistically significant difference in peak EMG activity in the VL muscle in the change of direction phase compared to the acceleration phase, $t(47)=-.980$, $p=.332$, $d=.141$. See Figure 12 for an illustration of these findings.

A one-way ANOVA was also conducted to determine if there were differences in peak EMG activity between the three muscles (GM, BF, and VL) during the acceleration phase of the agility test. The one-way ANOVA revealed no statistically significant differences in peak EMG activity between the three lower extremity muscles, $F(2,46)=1.814$, $p=.174$, $\eta^2=.073$. See Figure 13 for an illustration of these findings.

A one-way ANOVA was conducted to determine if there were differences in peak EMG activity between the three muscles (GM, BF, and VL) during the change of direction phase of the agility test. The one-way ANOVA revealed no statistically significant differences in peak EMG activity between the three lower extremity muscles during the acceleration phase, $F(2,46)=1.986$, $p=.149$, $\eta^2=.079$.

Figure 12.

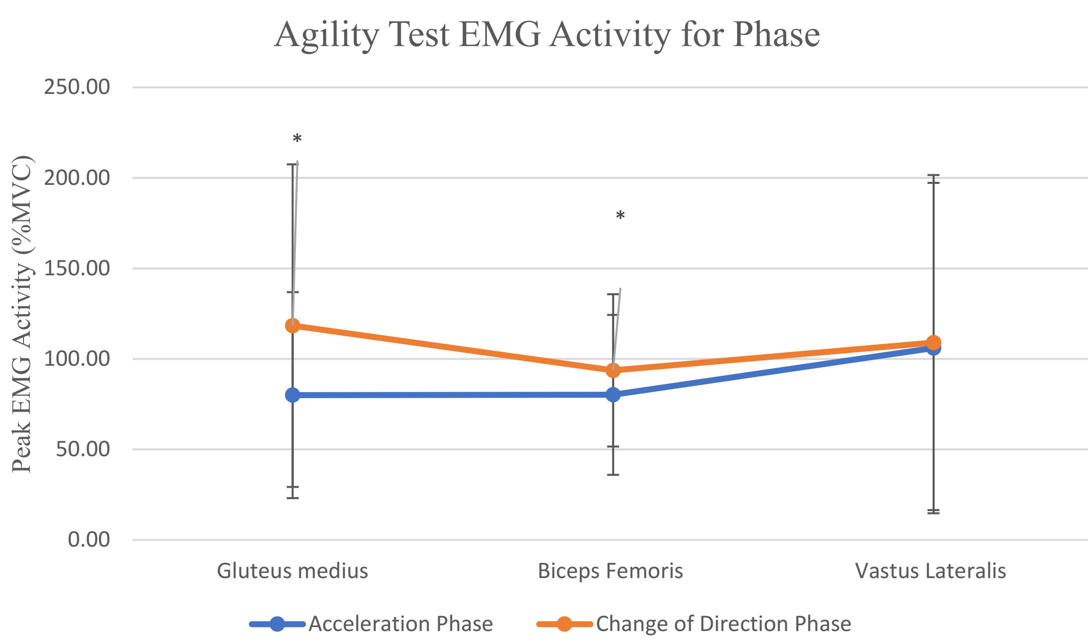
Y-shaped reactive agility test EMG activity by phase and muscle.



* Statistically significantly different from the acceleration phase ($p<.05$).

Figure 13.

Y-shaped reactive agility test EMG activity by muscle for each phase.



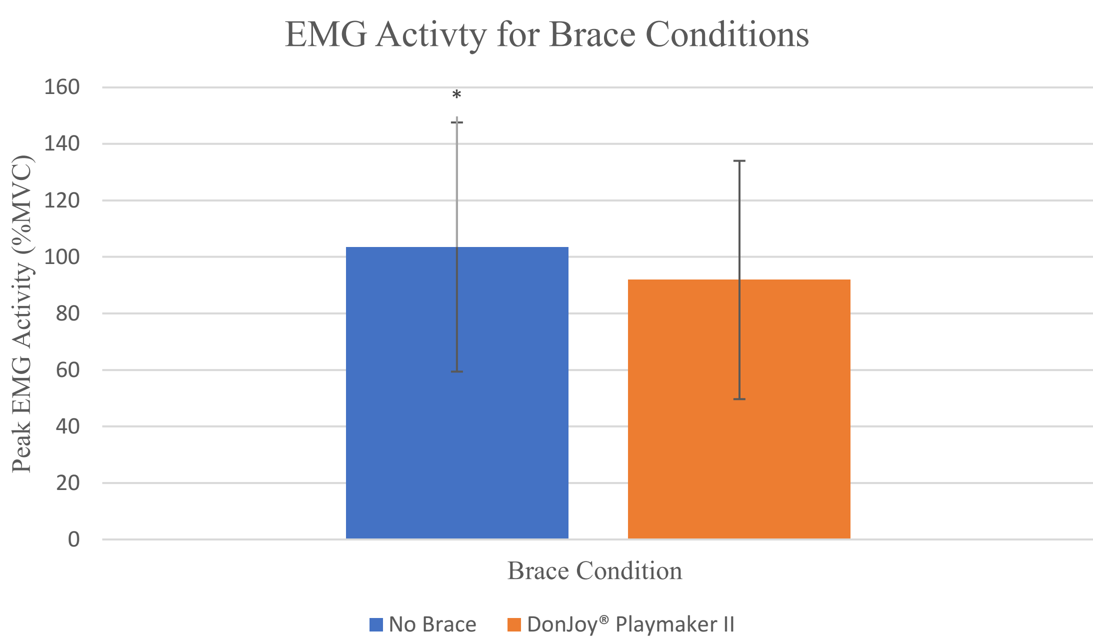
* Statistically significantly different from the acceleration phase ($p<.05$).

Two-way ANOVA – Brace and Muscle Type. The assumption of sphericity was not met, as assessed by the Mauchly's Test of Sphericity ($p=.007$). The Huynh-Feldt degrees of freedom value was utilized because the assumption of sphericity was violated ($\varepsilon = 0.773$). The two-way ANOVA did not reveal a statistically significant interaction in peak EMG activity during the Y-shaped reactive agility test, $F(2,22)=1.451$, $p=.256$, $\eta^2=.117$.

Main Effects – Brace Condition. The main effect of brace condition was analyzed on the total EMG activity. The main effect of brace condition revealed a statistically significant decrease in peak EMG activity between the no brace control 103.51+/-44.10 %MVC and the DonJoy® Playmaker II condition 91.85+/-42.18 %MVC with a large effect size, $F(1, 23)=4.467$, $p=.046$ $\eta^2=.163$. See Figure 14 for an illustration of these results.

Figure 14.

Main effects results for brace condition.

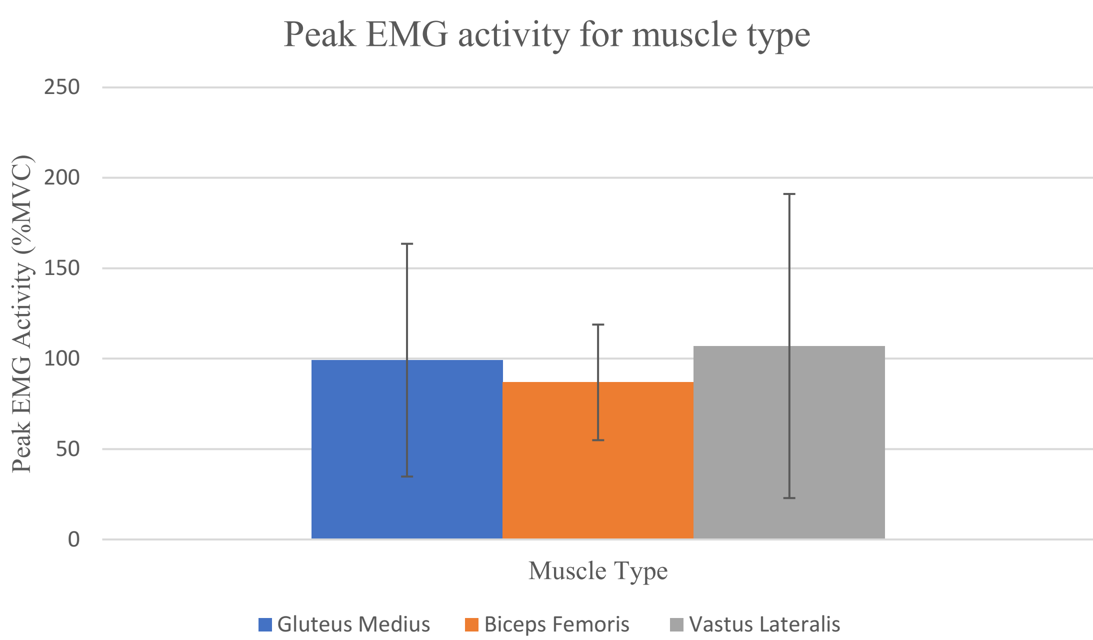


* Statistically significantly different from the DonJoy® Playmaker II condition (p<.05).

Main Effects – Muscle Type. The main effects of muscle type were analyzed on total EMG activity. The main effect of muscle type revealed no statistically significant difference between the three muscle groups on EMG (GM, BF, and VL), $F(1,23)=.689$, $p=.512$, $\eta^2=.059$. See Figure 15 for an illustration of these results.

Figure 15.

Main effects results for muscle type



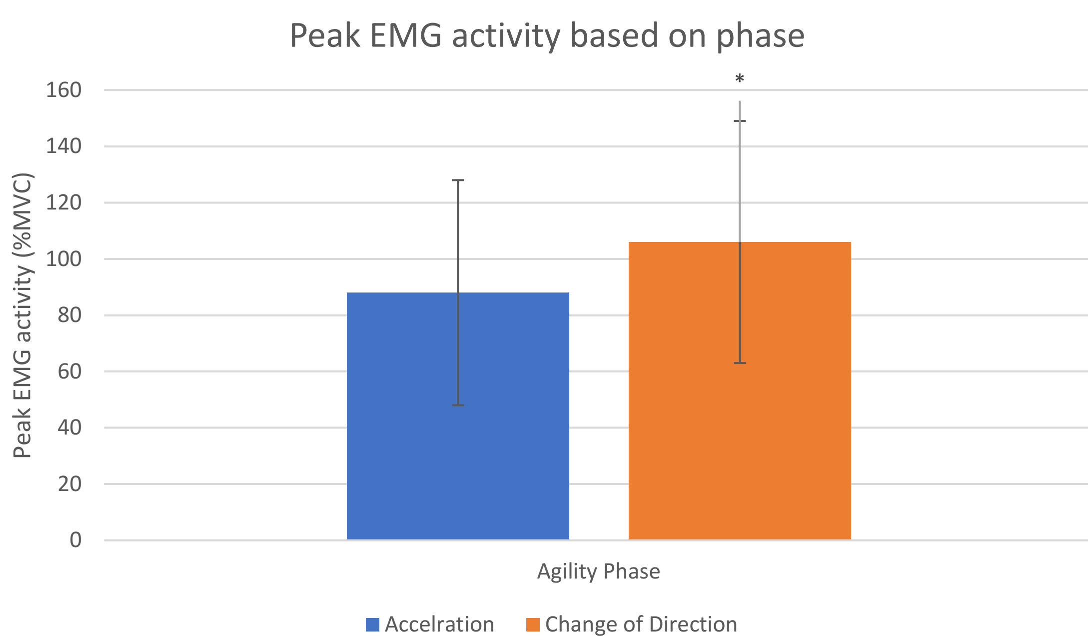
s

Two-Way ANOVA – Brace and Phase. The assumption of sphericity was not met, as assessed by the Mauchly's Test of Sphericity (p=.007). The Huynh-Feldt degrees of freedom value was utilized because the assumption of sphericity was violated (ε = 0.773). The two-way ANOVA did not reveal a statistically significant difference in peak EMG activity during the Y-shaped reactive agility test, $F(2,23)=1.944$, $p=.177$, $\eta^2=.078$.

Main Effects – Phase. The main effects of agility phase were analyzed on total EMG activity. The main effect of agility phase revealed a statistically significant increase in peak EMG activity between the acceleration phase 88.69+/-40.66 %MVC and the change of direction phase 106.67+/-43.45 %MVC with a large effect size, $F(1, 23)=21.306$, $p=.0001$ $\eta^2=.481$. See Figure 16 for an illustration of these results.

Figure 16.

Main effects results for agility phase.



* Statistically significantly different from the acceleration phase (p<.05).

Chapter 5: Discussion

The purpose of this pilot study was to examine differences between braced and non-braced soccer players on measures of reactive agility time (s), and EMG activity (% MVC) of the GM, BF, and VL during the acceleration and change of direction phases of the Y-shaped reactive agility test. To date, this was one of the first studies that measured agility test time and peak lower extremity EMG activity during a Y-shaped reactive agility test with and without the use of prophylactic knee braces in soccer player sample. This was also one of the first studies that measured GM EMG activity while wearing a prophylactic hinged knee brace. The results of this pilot study will contribute to the growing literature regarding the effects of knee braces on sports performance in healthy soccer players.

Question One: Is there a difference between the knee brace conditions (braced versus non-braced) for measures of reactive agility time (s) during a Y-shaped agility test?

Compared to wearing no knee brace, there was no statistically significant change in time to complete the Y-shaped agility test when wearing the DonJoy® Playmaker II knee brace. This amounted to an average time that was 0.03 s slower wearing the knee brace compared to no brace. Based on the data obtained in the current pilot study, healthy individuals who choose to wear a prophylactic hinged knee brace can expect to experience no meaningfully significant changes in reactive agility performance while reacting to a stimulus resulting in a 45° change of direction. These results can serve to benefit future researchers as literature evolves around the topic of reactive agility performance with the application of a knee brace.

To the researchers' knowledge, this is the first study to examine the reactive agility performance of healthy soccer players while wearing a knee brace. Although these results were analogous to Bodendorfer et al. (2019) and Rishiraj et al. (2011), there agility tests were not reactive and focused on 90° cutting tasks as opposed to a 45° task used in the current pilot study. Given that there is no previous research examining healthy participants during a reactive agility task while wearing a knee brace, it is difficult to compare and contrast the agility performance results of the Y-shaped reactive agility test to previous literature. Therefore, for the purposes of this discussion, comparisons will be made to studies utilizing different types of agility tests, knee braces, pathological populations, and preplanned compared to reactive agility tests.

There was no statistically significant difference found between the no brace control and braced conditions when comparing the reactive agility trial time. These results are in line with previous research conducted by Rishiraj et al. (2011) and Bodendorfer et al. (2019). Rishiraj et al. (2011) did not find any statistically significant differences on time during an agility T-test when participants wore a custom fitted FKB, however, the agility T-test did not incorporate a reactive component. Bodendorfer et al. (2019) examined time to complete a 90° cutting task when wearing a commercially available neoprene knee sleeve (Breg® Neoprene Knee Support, Breg®, Inc., Carlsbad, CA, USA) compared to a custom fitted prophylactic knee brace (Breg® Roadrunner™ Hinged Knee Brace, Breg®, Inc., Carlsbad, CA) on their dominant leg. Compared to the no brace control, both the neoprene knee sleeve and prophylactic knee brace did not significantly affect cutting time.

The function of a hinged prophylactic knee brace is to limit hyperextension of the knee to protect the ligaments of the knee (Rishiraj et al., 2012; Wirth et al., 1990). The reduction in hyperextension may coincide with some athletes' views that wearing a knee brace may limit their speed (Albright et al., 1995; Hewett et al., 2006). Despite athletes' views on the effect of knee braces, many researchers have also provided evidence that wearing a FKB in non-injured athletes does not hinder athletic performance (Greene et al., 2000; Rishiraj et al., 2000; Rishiraj et al., 2009a; Rishiraj et al., 2009b). Although the differences are not statistically significant, the slightly slower agility time in the braced condition in the present pilot study may be a result of participants not being acclimatized to the knee brace. Acclimation is defined as the adaptation to a new stimulus or condition presented (Gagnon & Crandall, 2018). Similar results regarding acclimation are also witnessed in a previous study by Rishiraj et al. (2011). The researchers found that earlier trials with the knee brace had slower but not statistically significant agility times compared to the no brace control, whereas no differences in performance were observed after the subjects wore the brace for a mean time of 14 hours. These results indicate that any change in performance may be temporary and that performance levels may adjust to non-braced levels around the 14 hour timeframe when wearing a knee brace. The present pilot study did not observe or account for acclimation as participants were not tested over a period of time, but rather immediately after application of the knee brace. Although no statistically significant differences in agility times were found in both studies, agility time while wearing the knee brace may have more closely resembled the no brace condition because of the type of knee brace used. Rishiraj et al. (2011) used a custom fitted FKB, while the current pilot study used an off-the-shelf prophylactic knee brace. The small differences between agility trial times may have been attributed to other factors that were previously reported, such as the type of knee brace used and the design and materials of the knee brace (Greene et al., 2000).

Greene et al. (2000) evaluated the effects of several knee brace models on the speed and agility of college football players. They measured agility time during a four-cone agility drill in all six knee brace conditions and compared them to the no brace control. One of the prophylactic knee braces used in the study, the Air Armour© 2 Knee and Thigh Protection System (Air Armor, Inc., Scottsdale, Arizona, USA), had a similar design to the prophylactic knee brace used in the present pilot study (DonJoy® Playmaker II). Both knee braces resulted in no statistically significant differences in agility time when compared to the no brace controls. These knee braces were primarily made from the same materials including neoprene and elastane. The Breg® Tradition (Breg, Inc., Vista, California, USA) was another knee brace that Greene et al. (2000) included and tested. This knee brace is considered a FKB and was designed with much more rigid materials including hard plastic and aluminum. The use of this knee brace resulted in statistically significantly slower agility time when compared to the no brace control condition. The similar results from the previous study using the Air Armour© knee brace and present study, using the DonJoy® Playmaker II knee brace may suggest that agility time is not statistically significantly affected while wearing prophylactic knee brace models of a similar design, whereas FKBs knee braces made from more rigid materials may result in slower agility times. The researchers noted that due to the knee braces design, these results may only be applicable to knee braces of a similar design and material. The type of agility test may have also been a contributing factor to the agility test time as the added stimulus presented during a reactive agility test may lead to kinematic and performance based differences compared to a pre-planned agility task.

Wheeler and Sayers (2010) examined the differences in pre-planned versus reactive agility performance during a Y-shaped agility test in healthy male rugby players. They compared the running speed between the pre-planned and reactive agility conditions in both the pre-change of direction and change of direction phases of the Y-shaped agility test. The researchers found that in both the pre-change of direction phase and change of direction phase, running speed was slightly higher during the reactive condition compared to the pre-planned agility task. The methodological approach for the present pilot study was structured similarly to that of Wheeler and Sayer (2010) based on the rationale that reactive agility scenarios more closely resembled sport specific performance. Wheeler and Sayers (2010) investigated the differences in agility speed between pre-planned and reactive agility performance conditions whereas the current pilot study focused solely on reactive agility and the role a prophylactic knee brace plays during the agility task.

Wheeler and Sayers (2010) included eight healthy high performance male rugby players, whereas the current pilot study recruited 24 healthy soccer players (14 males and 10 females; M=23, SD=4 years) from various experience levels (1 semi-professional. 3 collegiate, 9 varsity, and 11 recreational). The researchers found that running speeds in both the pre-change of direction and change of direction phases were slightly higher during the reactive condition compared to the pre-planned agility task. The small sample size, consisting of high performance male rugby players, may have limited the generalizability of the results to other females and athletes of other sports. Therefore, the results for Wheeler and Sayers (2010) may not represent what females and other athletes may experience during similar movements. A much larger sample of participants across different sports needs to be compared in future studies, but the preliminary results of these studies support further examination into this area.

Farrow et al. (2005) had participants perform a Y-shaped agility test in both pre-planned and reactive conditions. For the reactive condition, participants were required to cut towards the direction of a pass produced by a player on a video display. Farrow et al. (2005) demonstrated that high performance netball athletes have faster decision-making skills over less skilled athletes during reactive agility tasks involving sports related stimuli. Higher skilled players ability to anticipate the pass direction was evidenced by lower mean decision-making time compared to the less skilled players, allowing the higher skilled players to predict the reactive component sooner. Higher skilled players are able to anticipate these movements sooner, partially due to the repetitive nature of sports specific tasks (Farrow et al., 2005). A possible explanation for the non-significant results in reactive agility times in the present pilot study may be due to the fact that all the participants in the present pilot study had no prior experience wearing a knee brace. This suggests that movement adaptations were not made by the participants during the performance of the Y shaped reactive agility test while wearing a knee brace, resulting incomparable times between brace conditions. Studies have shown that knee braces do not significantly affect agility time during pre-planned tasks either.

Bodendorfer et al. (2019) examined the effects of a neoprene knee sleeve (Breg® Neoprene Knee Support, Breg, Inc., Carlsbad, CA, USA) and a custom-fitted prophylactic knee brace (Breg® Road Runner Hinged Knee Brace, Breg, Carlsbad, CA, USA) compared to a no brace control on cutting agility during a simulated 90° cutting manoeuvre in a healthy athletic sample. The researchers identified that cutting agility time was not statistically significantly different with either the neoprene knee sleeve or the prophylactic knee brace compared to the no brace control. The results from the present pilot study are in line with the results obtained by Bodendorfer et al. (2019). Similar to what Greene et al. (2000) noted, Bodendorfer et al. (2019) noted that the results obtained in their study may only be applicable to the knee brace used in their study. Therefore, the results obtained in the current pilot study may only apply to the DonJoy® Playmaker II prophylactic knee brace and it may be inappropriate to generalize these results to other prophylactic knee braces or other knee braces. The injury status of participants and bracings effect during agility testing has also been previously investigated.

Dickerson et al. (2020) examined whether physical performance would be altered in athletes recovering from ACL reconstruction during the first three months after returning to sport while wearing a custom-fitted FKB. Participants completed an agility T-test and included sprinting forward, side shuffling to both sides, and back peddling. Participants completed the test during the return to sport period and at a three-month follow-up. There were no statistically significant differences in total agility, sprint, side shuffle, and back peddle times while wearing the FKB at both the return to sport and three-month follow-up periods. Contrary to Dickerson et al. (2020), the present pilot study did not include side shuffling and back peddling movements and primarily focused on examining reactive agility time while running in a forward direction. While side shuffling and back peddling are both core movements in soccer (Grooms et al., 2013), their study did not address reactive agility time, which is also a fundamental component of soccer and other field sports (Bompa & Haff, 2009). The results from Dickerson et al. (2020) and the current pilot study may suggest that agility performance, whether pre-planned or reactive, is unaffected when wearing a knee brace in both healthy and ACL reconstructed individuals.

The non-significant results in the present pilot study were expected due to the relatively small moment where the participants were required to change directions to either the left or right compared to the rest of the agility test. The intent of the present pilot study was to examine if a prophylactic hinged knee brace affected reactive agility time. Based on previous literature surrounding the use of knee braces on agility performance, results have been mixed with researchers showing no change in time (Bodendorfer et al., 2019), slower times (Greene et al., 2000), and faster times the longer participants wore the brace (Rishiraj et al., 2011). The participants recruited also varied from study to study. Bodendorfer et al. (2019) and Rishiraj et al. (2011) recruited healthy recreational athletes and healthy collegiate athletes, respectively. While the present pilot study did not focus specifically on the performance level of participants, it did try to limit the variability caused by performance level by recruiting soccer players solely. The sample that was recruited for the present pilot study was primarily made up of recreational and former varsity athletes, with only three current or former collegiate athletes and one semi-professional athlete. The training regimen for collegiate and semi-professional athletes is likely more rigorous than that for varsity and reactional athletes. The differences in training protocols and skill levels may have affected the results as there was a potential for higher-skilled athletes to exhibit faster agility times compared lower skilled athletes (Hachana et al., 2014). The results from the present pilot study compared to similar findings reported from previous studies indicate that agility time while wearing a knee brace in healthy controls may not be significant in both change of direction and reactive agility tasks.

Based on the results obtained from the current pilot study, the application of a knee brace did not significantly affect the agility time during a reactive agility test. Healthy soccer players should not expect significant changes in agility performance while wearing a hinged prophylactic knee brace.

Question Two: Is there an interaction effect between the knee brace conditions (braced versus non-braced), muscle type (GM, BF, and VL muscles), and phase (acceleration and cutting) for measures of lower extremity EMG muscle activity during a Y-shaped agility test?

There was no statistically significant three-way interaction affect between bracing condition, muscle type, and phase for measures of EMG muscle activity during the Y-shaped reactive agility test. Compared to the no brace control, there was no statistically significant differences in EMG activity in any of the three muscles tested regardless of agility phase. These results may indicate that healthy individuals wearing a prophylactic hinged knee brace may experience no statistically significant alternations in EMG activity for the GM, BF, and VL muscles while reacting to a stimulus resulting in a 45° change of direction. These results may serve to benefit future researchers as literature evolves around the effects of EMG muscle activity during reactive agility measures with the application of a knee brace.

To the researchers' knowledge, this is one of the first studies to examine the EMG muscle activity of healthy participants during a reactive agility test while wearing a knee brace. These results were comparable to Branch et al. (1989), however, the participants recruited for the previous study were ACL deficient and the side cutting maneuver participants performed was not reactive nor was the angle of the cutting maneuver mentioned in the previous literature. Given that there is no previous research directly examining lower extremity EMG activity of healthy participants during a reactive agility test while wearing a knee brace, it is difficult to compare and contract the EMG activity results from the current pilot study to previous literature. Therefore, for the purposes of this discussion, comparisons will be made to studies utilizing different movement characteristics for each of the three muscles tested (GM, BF, and VL muscles), how changes in EMG activity can affect injury rates, how the application of a knee brace affects EMG activity, and studies examining the application of knee braces.

There was a significant interaction effect on EMG activity between agility phase and muscle type during the reactive agility test. Further analysis revealed that the GM and BF muscles increased in EMG muscle activity during the change of direction phase compared to the acceleration phase, whereas the VL EMG muscle activity was not significantly affected.

The three-way ANOVA revealed no statistically significant interaction effect on EMG muscle activity during the Y-shaped reactive agility test between the knee brace condition, muscle type, and phase. Although there were no statistically significant differences, it should be noted that the VL EMG muscle activity was the highest among all three muscles regardless of brace condition and phase. These results are similar to previous literature which found that the quadriceps muscle group produced the greatest EMG muscle activity in the lower extremities during the stance phase of a cutting maneuver in braced and non-braced individuals (Branch et al., 1989). While there were no statistically significant differences in the three-way ANOVA, there were statistically significant differences in the two-way interaction between the phase and muscle type, with the GM muscle showing increased EMG muscle activity during the change of direction phase. This may be due to increases in GM EMG muscle activity during a cutting or change of direction movement compared to straight line running, support for this rationale can be found in research examining the effects of different maneuvers on GM muscle activity.

This statistically significant difference may be because the GM muscle is responsible for hip abduction which partially occurs in the planting leg during a cutting task. Previous literature has highlighted the importance of the GM muscle during sidestep cutting maneuvers for accelerating the body toward the desired target location (Maniar et al., 2019). The GM muscle is a pelvic stabilizer, which is responsible for hip abduction in order to shift the centre of mass outside an individual's bass of support, resulting in a change of direction (Maniar et al., 2019). This may be the reason why the GM muscle was activated more during the change of direction phase in comparison to the acceleration phase regardless of bracing condition. There was no statistically significant difference in GM EMG muscle activity in both the acceleration and change of direction phases, with respect to the bracing condition. The GM muscle has also been shown to provide the greatest contribution to lateral knee joint movements during side cutting maneuvers (Maniar et al., 2018). Sidestep cutting is typically associated with valgus loading (Besier et al., 2001), which is thought to contribute to non-contact injury mechanisms in the knee joint (Krosshau et al., 2007; Olsen et al., 2004). The increased EMG activity in the GM muscle during the change of direction phase in the present pilot study, coupled with previous literature, may suggest that the GM muscle may be an important muscle to target for regular training regimens and injury prevention programs for soccer players as they routinely perform cutting maneuvers and directional changes.

While the application of a knee brace did not statistically significantly affect GM EMG muscle activity, there was a slight decrease in GM EMG muscle activity during the change of direction phase once the knee brace was applied. Therefore, the results from the current pilot study coupled with previous literature may suggest that individuals wearing a knee brace can expect no changes in GM muscle activity. Individuals wearing a knee brace may want to consider strengthening of the GM muscle during training more than their non-braced counterparts. While differences in EMG muscle activity were not statistically different between the bracing conditions, there was a non-significant increase in EMG activity in the GM muscle while wearing the knee brace during the acceleration phase. Whereas, during the change of direction phase, the GM EMG activity decreased slightly. Previous literature has shown that increased GM EMG muscle activity during running tasks have been associated with an increase in hamstring injuries in elite-level Australian football players (Franettovich-Smith et al., 2017). While Franettovich-Smith et al. (2017) did not measure muscle activity in the hamstring muscles, a possible explanation for the increase in hamstring injuries may be that the GM muscle may have been compensating for a deficit in other hip and pelvic muscles. The current pilot study found that BF EMG muscle activity also increased when the knee brace was applied during the acceleration phase. These results indicate that further research is required to determine if increased GM muscle activity may also coincide with increased BF muscle activity when wearing a knee brace while running. These results may be two-fold, if BF muscle activity increases with GM muscle activity, it would be beneficial for ACL deficient individuals who wear a knee brace, as increased BF EMG muscle activity reduces anterior shear forces acting on the knee (Azmi et al., 2018). If BF muscle activity increases with GM muscle activity it, however, may also increase their risk of incurring hamstring injuries. While the study by Franettovich et al. (2017) did not measure muscle activity in the hamstring muscles, it did find that increased GM muscle activity was a risk factor for hamstring injuries. Hamstring injuries in soccer players are already high representing 12% of all injuries in high level players (Ekstrand et al., 2011). Further research is needed to determine if the effects of prolonged knee bracing on EMG activity during running and cutting activities is beneficial for individuals.

The non-significant decrease in GM EMG muscle activity during the change of direction phase between the braced condition is interesting as GM muscle activation tends to increase during cutting movements. Kim et al. (2019) found non-significant decreases in GM EMG muscle activation during the initial movement of a cutting phase following a vertical jump while wearing a knee brace. It should be noted that the knee brace used was a varus unloading knee brace, which contains only one hinge on the lateral aspect of the knee, as opposed to the DonJoy® Playmaker II knee brace used in the present pilot study, which contained bilateral hinges. Kim et al. (2019) also recruited participants with chronic ankle instability for their study, therefore, relating the findings to the present pilot study is difficult. These results may suggest that during activities that require cutting, the use of a knee brace may limit the amount of muscle activity in the GM muscle. This may result in athletes having less explosive movements during cutting activities and may require athletes to incorporate more training targeting the GM muscle to compensate for this potential deficit. Kim et al. (2019) also noted that during a landing task in patients with chronic ankle instability increased co-activation of the GM and abductor longus muscles increased frontal-plane hip joint stability. Therefore, the decrease in GM muscle activity may partially negatively affect hip joint stability. This is the first study to have examined GM EMG muscle activity during a cutting activity while wearing a knee brace. As a result, future research regarding knee braces should focus on activities that require increased muscle activation and muscular control to determine if similar results are found.

There was a statistically significant increase in BF EMG muscle activity in the change of direction phase compared to the acceleration phase. This statistically significant increase may be because the BF muscle is primarily responsible for hip extension, which occurs during the push off phase of a directional change (Anderson et al., 2017). Ciccotti et al. (1994), examined the EMG muscle activity of the vastus medialis oblique, VL, rectus femoris, semimembranosus, BF, tibialis anterior, gastrocnemius, and soleus muscles during running and directional change movements at fixed speeds. Ciccotti et al. (1994) found that the BF EMG muscle activity greatly increased during the stance phase of the change of direction maneuver. The results from the present pilot study align with those found by Ciccotti et al. (1994) suggesting that directional change movements may require more BF muscle activity compared to the normal gait cycle during running. The need for increased BF muscle activity may be because the change of direction movements involved more explosive movements, and increased BF muscle activity is needed to position the hip into extension during the moment of a directional change. Ciccotti et al. (1994) found that increased BF muscle activation is beneficial during cutting maneuvers as it can resist anterior tibial rotary forces generated via the contralateral limb.

Hinged knee braces increase functional stability at the knee joint following an injury by reducing anterior shear forces (Vailas & Pink, 1993). Increasing EMG activity in the hamstring muscle group is one method to reduce anterior shear forces acting on the knee (Kingma et al., 2004), with the long head of the BF muscle offering the greatest reduction to anterior shear forces (Azmi et al., 2018). While there were no statistically significant differences in EMG muscle activity between bracing conditions, there was a noticeable increase in EMG activity of the BF muscle in the braced condition during the acceleration phase. These results may be important to individuals who wear a knee brace and have incurred an ACL injury, due to the role BF muscle activity plays on anterior shear forces. During the change of direction phase, BF EMG muscle activity slightly decreased but non-significantly while wearing the knee brace. The results from the present pilot study are also consistent with the results found by Théoret and Lamontagne (2006), where increased but not statistically significant differences in EMG activity in the BF muscle during running was reported. Théoret and Lamontagne (2006), however, examined ACL deficient individuals, whereas the current pilot study only recruited healthy individuals. Théoret and Lamontagne (2006) postulated that the application of a knee brace on an ACL deficient limb, increased the EMG activity. The results from the present pilot study may suggest that similar muscular activation patterns are found in healthy controls during a running task but may be specific to the phase of the task.

During the change of direction phase, although not statistically significant, the EMG activity in the BF muscle decreased in the braced condition compared to the non-braced condition. These results contradict the previous notion that the application of a knee brace increases BF EMG muscle activity by reducing anterior shear forces and any reduction in activity in the hamstring muscle may be detrimental to individuals with certain types of knee injuries.

The research surrounding BF EMG muscle activity during cutting activities while braced is sparse. Branch et al. (1989) noted that with ACL deficient subjects, during the stance phase of a change of direction movement, an increase in semitendinosus and semimembranosus EMG muscle activity was found. This may suggest that during the stance phase of a change of direction movement, BF muscle activity may not be as important for maintaining stability in the knee during a change of direction movement as other parts of the hamstring muscle. The authors suggested that EMG muscle activity in the semitendinosus and semimembranosus may be more important during cutting and change of direction movements.

The VL was the final muscle that was measured during the reactive agility task and there was no statistically significant differences in VL EMG muscle activity between the acceleration and change of direction phases. The observed mean EMG activity in the VL between the acceleration and change of direction phases were near identical in both the braced and non-braced conditions. These results contradict those found by Hanson et al. (2008), who found that VL EMG activity increased during the loading phase compared to the preparatory phase of a side-step cutting maneuver in both healthy colligate level males and females. They noted that females had greater VL EMG activation than males, although these sex differences in VL muscle activity were not attributable to performance differences. Greater VL muscle activation during the loading phase may have been related to sex differences in the landing kinematics of a cutting maneuver (Sigward & Powers, 2006), as females require greater muscle recruitment from the quadriceps muscle group. The authors also noted that the difference in VL muscle recruitment was also found during the preparatory phase between sexes. They postulated that the greater VL muscle activity in both phases during side-step cutting maneuvers may be due to a simultaneous increase in muscle activity between the agonist and antagonistic muscles (Hanson et al., 2008). When an agonist-antagonist pair of muscles are performing a specific task, the motor units of each muscle employ both muscles as a single entity (De Luca & Mabrito, 1987). In the current pilot study, the noticeable increase in BF EMG muscle activity with a lack of increase in VL

EMG muscle activity may indicate that the simultaneous increase in agonist-antagonist muscles may not apply to reactive movements. This conclusion was also proposed by Hanson et al. (2008), who noted that greater VL muscle activity during the loading phase of a cutting maneuver may represent differences in pre-planned and reactive VL muscle activity.

The current pilot study found no statistically significant differences in VL muscle activity between bracing conditions during the acceleration and change of direction phases. As previously mentioned, increasing EMG activity in the hamstring muscle group has been shown to reduce anterior shear forces, with the long head of the BF muscle contributing to the greatest reduction in force (Azmi et al., 2018; Kingma et al., 2004). The VL muscle is one of the antagonistic muscles of the hamstring muscle group. In the present pilot study, the increase in BF muscle activity during the acceleration phase of the reactive agility test may explain why VL muscle activity decreased, due to the hamstring-quadriceps agonist-antagonist coactivation. Similar results were found by Théoret and Lamontagne (2006) in ACL deficient participants during a straight-line running task. Therefore, it may be more appropriate to state the results of the VL muscle during the agility test were due to the VL muscle playing an antagonistic role to the BF and other hamstring muscles.

Although there were no statistically significant differences between bracing conditions, it should be noted that statistically significant differences between phase and muscle type were found during the agility test. Previous literature has identified that GM muscle activity plays a crucial role in lower extremity muscle activation during cutting maneuvers (Maniar et al., 2019), while BF muscle activity also increases during cutting maneuvers (Ciccotti et al., 1994). The differences in muscle activity may have been due to the different nature of the movements between straight-line running in the acceleration phase and the cutting maneuver in the change of direction phase. The increases in BF EMG muscle activity while wearing the knee brace may have been due to increased muscle activity as a means for reducing anterior shear forces.

Limitations

Some limitations were identified during the completion of this pilot study. First, it is important to address the sample size recruited as insufficient power was obtained. A larger sample size is needed for future research to be able to complete a more comprehensive analysis of the impact knee braces have on EMG muscle activity and be able to confidently detect the changes in the results of the analysis.

Another limitation in using EMG as part of the design methodology is that cross talk may have occurred impacting on the muscle activity recorded. While electrode placement was standardized following the SENIAM guidelines, crosstalk errors may have occurred via the neighbouring muscles. Crosstalk occurs when performing an action to stimulate one muscle creates an undesired effect in another muscle (He et al., 2020). In the present pilot study, the undesired activation of neighbouring muscles was likely picked up by the EMG sensors for the muscles that were being tested, resulting in possibly altered EMG results for some participants. The effect of crosstalk may have influenced the %MVC results of this pilot study and muscle be considered. The use of fine wire EMG sensors over surface electrodes may help to eliminate any crosstalk between neighbouring muscles.

As this pilot study was exploratory in nature, the analysis did not control for independent variables such as sex or knee bracing experience, which could have influenced the dependent variables collected in the present pilot study. Anatomical differences between males and females, such as tibial and thigh length and height (Hewett et al., 2006; Uhorchak et al., 2003) and increased VL EMG activity in females during side-cutting maneuvers (Sigward & Powers, 2006), may have influenced the results due to not accounting for sex differences. Knee bracing experience is another limitation of the present pilot study, as previous research has shown that performance differences tend to normalize to non-braced levels after 14 hours of wearing a knee brace (Rishiraj et al., 2011). All participants recruited in the present pilot study had no prior experience using a hinged knee brace, which may have affected the results of the present pilot study and may not truly represent performance differences due to wearing a hinged prophylactic knee brace. The present pilot study also only tested the acute effects of knee brace application, which may have influenced the results of the present pilot study and may not resemble what reactive agility performance looks like after individuals have acclimated to the knee brace.

Future Research

Future research should consider incorporating other regularly performed movements in soccer (e.g., kicking, side shuffling, back peddling, and cutting backwards), as well as using a healthy and a pathological population, such as ACL deficient individuals, as knee brace use is more often used in this group and allows for direct comparison to healthy individuals.

Although not directly analyzed in the current pilot study, sex differences in muscle activation during cutting maneuvers should also be compared and addressed. Compared to males, females are 1.7 times more likely to incur an ACL injury (Montalvo et al., 2018). This increase in injury rate may be due to many reasons, and future research should consider the influence sex may have on knee bracing’s effects on lower extremity muscle activity during different sport related tasks.

Additionally, future research should incorporate kinematic and kinetic analysis coupled with EMG data to improve the interpretation of the results. Kinematics and kinetics may help determine differences in movements during various soccer tasks and can help researchers better discern differences while wearing a knee brace and understand those changes. The incorporation of GRFs during reactive agility and other regularly performed movements during soccer may be important for determining performance differences while wearing a knee brace and may help researchers understand the forces the knee and neighbouring joints experience during these movements.

Chapter 6: Conclusion

The purpose of this pilot study was to examine differences between braced and non-braced soccer players on measures of reactive agility time (s), and EMG activity (% MVC) of the GM, BF, and VL during the acceleration and change of direction phases of the reactive agility test. The current pilot study builds on the previous literature examining the effects of knee braces on agility measures and adds to the limited literature examining lower extremity EMG activity during reactive agility tasks (Bodendorfer et al., 2019; Rishiraj et al., 2012).

The trial time results of the current pilot study are in line with previous studies, in that the application of a hinged prophylactic knee brace does not significantly affect agility trial time. Soccer players can expect no change in performance when performing reactive agility tasks. The use of a hinged prophylactic knee brace did not influence the EMG muscle activity of lower extremity muscles during both the acceleration and change of direction phases of a reactive agility test. The present pilot study found a statistically significant difference in muscle activity between the acceleration and change of direction phase, indicating that muscle activity may be altered between running and cutting tasks. Further and more comprehensive research is needed incorporating a variety of movements and sport specific skills, evaluating sex differences, and adopting combined kinematic, kinematic, and EMG analyses following knee brace application over an extended period of time to determine the effects of a knee brace. While research continues to advance, soccer athletes should continue to follow the recommendations of their healthcare providers while weighing the pros and cons when it comes to the application of a knee brace in sports. This study provides insight that no differences in performance time or EMG muscle activity were found during the reactive agility task.

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Appendix A

Recruitment Poster

Lakehead UNIVERSITY | School of Kinesiology

PARTICIPANTS WANTED!

Effects of Knee Bracing on Agility and Kicking performance in healthy soccer players

Conducted by:

James Fimognari
School of Kinesiology
Lakehead University

- **Healthy, active individuals between the ages of 18 and 40 who participate in at least 150 minutes of moderate physical activity per week**
- **Previous or experience playing soccer**
- **have not been diagnosed with a lower-body or low back injury (fracture, sprain, strain, surgery) in the past year that prevents participation in soccer.**

All measurements are non-invasive and all information collected is confidential and anonymous. You will be tested during one 60 minute session. You will be asked to perform a kicking drill and an agility test. each of these tasks will be performed on the turf at the hanger. Your ankle velocity, agility time, and muscle activity will be measured with and without a knee brace.

For more information, or to volunteer please contact

James Fimognari

jfimogna@lakeheadu.ca

This project was reviewed by LakeheadU REB #1469253

Appendix B

Information Letter

Lakehead UNIVERSITY

School of Kinesiology
t: (807) 343-8514
f: (807) 343-8944
e: kinesiology@lakeheadu.ca

Dear Potential Participant,

Thank you for expressing interest in this pilot study entitled "The Effects of Knee Bracing on Reactive Agility and Kicking Performance Among Healthy Soccer Players." I am a Lakehead University graduate student in the School of Kinesiology, and I will be undertaking this pilot study under the supervision of Dr. Paolo Sanzo, Associate Professor in the School of Kinesiology at Lakehead University. You have been invited to participate in this pilot study because you are a physically active individual, who participates in at least 150 minutes of physical activity per week, have had previous or current experience playing soccer and are between the ages of 18-40 years of age. You are also not suffering from a low body or low back injury, such as a strain or sprain preventing you from running, cutting, or kicking. You must also not have suffered a knee injury within the last year that has required you to or still requires bracing because of the injury. You must also not be allergic to any materials commonly used in knee braces (neoprene, elastane, cellulose, or synthetic rubber), adhesive materials, or currently being pregnant. These are the criteria for individuals to be included in this study.

PURPOSE

The purpose of this pilot study will be to see if wearing a knee brace affects reactive agility time, muscle activation during an agility test, and foot acceleration for 18 healthy, active individuals. This will be done by having you run through an agility test and a maximal instep kick drill. These tasks will involve you quickly running and then changing direction and kicking a soccer ball. Additionally, sensors will be placed on your leg muscles to measure muscle activation during the agility test and an additional sensor on your cleat to measure foot acceleration. You will perform these tasks both with and without a knee brace.

WHAT INFORMATION WILL BE COLLECTED?

During your participation in this study, the information collected from this study will include your demographic data (sex, height, weight, and soccer experience level), your muscle activity of your gluteus medius, vastus lateralis, and biceps femoris muscles during the completion of the reactive agility test, the time to complete the reactivity agility test, and your foot acceleration during a kicking trial.

WHAT IS REQUESTED OF ME AS A PARTICIPANT?

As a participant, you will be asked to sign up for one testing session. This session will last approximately 60 minutes and will take place in room SB-1028 and the Lakehead University Hangar. Upon arriving for your testing session, you will be asked to complete a consent form indicating that you know your rights as a participant. At this time, you also can ask any questions that you may have about the pilot study. You will then be asked to fill out a Physical Activity Readiness Questionnaire (PAR-Q+) to ensure you can safely participate in this pilot study. Before beginning the active portion of the pilot study, your demographic data will be recorded (sex, height, weight, and soccer experience level). You will also be assigned the order to wear the knee brace for the agility and kicking tasks.

For the active portion of the study, you will be asked to perform on an indoor soccer field. You will begin with a 5-minute warmup which will consist of jogging and short accelerations. After you have completed the warmup, the student researcher will place small surface electrode sensors on your leg and thigh muscles. Once the electrodes have been applied, you will perform a series of muscle contractions while the researcher provides resistance. Following this, you will perform the reactive agility test with your first assigned knee brace condition (no brace or braced) six times; two familiarization trials, followed by four best effort trials. After you have completed the agility test with the first knee brace condition, you will then switch to the following knee brace condition. You will complete two familiarization trials and four best effort trials again. After completing the reactive agility test, you will complete a kicking drill, where you will kick a soccer ball as hard as possible. An additional electrode will be placed on the top of your cleat to measure your foot acceleration during the kick. You will complete this drill under both knee brace conditions. The session will be completed after you complete a 5-minute jogging cooldown.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

As a researcher, is my responsibility to inform you of your rights as a participant. You must understand that as a participant, your participation is completely voluntary. Your decision to participate in this pilot study will not affect your current or future academic or employment status at Lakehead University. As a participant, you have the right to remain confidential. To ensure this, all results from the pilot study will be presented confidential, and your name will be replaced with a unique number. The data will only be accessible to the researchers conducting the study (e.g., Dr. Paolo Sanzo and James Fimognari). If the data is presented to the public as a written report or publication, or in the form of a verbal presentation, yours and all other participant data will remain condifential. You may refuse to answer any questions or refuse to partake in any activity at any time throughout the study. You may also withdraw from the pilot study at any time without penalty.

WHAT ARE THE RISKS AND BENEFITS?

There will be no direct physical harm to you as a participant completing the pilot study, however, there is a minor risk that you may sustain a strain or sprain, because of participating in these tests. This risk will be minimized as you will perform the activity on a safe, dry, flat, and even surface under the direct supervision of the graduate researcher. These factors will assist in preventing any falls or other physical harm to you as the participant. As you are a healthy and active individual, any potential risk will be minimized. In the unlikely event that you do sustain an injury while participating in the pilot study, the student researcher on hand is trained in first aid and CPR.

The results from this pilot study may benefit society in that it may reveal the effects of wearing a knee brace on soccer performance measures, foot acceleration, and muscle activation of the lower body. This information can potentially be used by athletes, coaches, and healthcare providers when considering prophylactic knee braces for soccer use.

HOW WILL MY CONFIDENTIALITY BE MAINTIANED?

As a participant, you have the right to remain anonymous. To ensure this, all results from the pilot study will be presented confidentially, and your name will be replaced with a unique number. The data will only be accessible to the researchers conducting the study (e.g., Dr. Paolo Sanzo and James Fimognari). If your data is presented to the public as a written report or publication or a verbal presentation, all participant data will remain confidential.

WHAT WILL MY DATA BE USED FOR?

Your data will be used to determine if there is any effect on the leg and thigh muscle's activity while wearing a knee brace. Your data also be used to determine if wearing a knee brace affects reactive agility trial time and foot acceleration during a soccer kick.

WHERE WILL MY DATA BE STORED?

Your data will be stored at Lakehead University in the office of Dr. Paolo Sanzo for a minimum of five years following completion of the research report.

HOW CAN I RECEEIVE A COPY OF THE RESEARCH RESULTS?

If you desire, a written copy of your results will be made available to you upon request. The written summary of your results will be sent to you via the email address you indicated on the consent form.

WHAT IF I WANT TO WITHDRAW FROM THE STUDY?

You may refuse to answer any questions or refuse to partake in any activity at any time throughout the pilot study. You may also withdraw from the pilot study at any time without penalty.

INFORMATION REGARDING COVID-19

This research study is taking place on Lakehead University campus. Lakehead University has a mandatory vaccine requirement for all individuals coming on campus. You will be asked to provide proof of vaccination to the research team. Proof of vaccination can be provided in one of three ways: 1) Ministry of Health proof of vaccination document along with government issues photo ID, 2) Ontario vaccine passport along with a government issued photo ID, or 3) Lakehead University MobileSAFETY app.

RESEARCHER CONTACT INFORMATION

James Fimognari, HBK
jfimogna@lakeheadu.ca
(807) 620-5743

Dr. Paolo Sanzo, DSc, MSc, BScPT, FCAMPT
psanzo@lakeheadu.ca
(807) 343-8647

This pilot study has been approved by the Lakehead University Research Ethics Board. If you have any questions related to the ethics of the research and would like to speak to someone outside of the research team please contact Sue Wright at the Research Ethics Board at 807-343-8283 or research@lakeheadu.ca.

Appendix C

Informed Consent Form

Lakehead UNIVERSITY

School of Kinesiology
t: (807) 343-8514
f: (807) 343-8944
e: kinesiology@lakeheadu.ca

MY CONSENT:

I agree to the following:

- I have read and understand all the information contained in the Information Letter.
- I agree to participate.
- I understand the potential risks and benefits of the pilot study.
- I understand that as a volunteer, I may withdraw at anytime throughout the pilot study and may refuse to perform any activities with no penalty or consequences.
- That the data will be securely stored at Lakehead University in the office of Dr. Paolo Sanzo for a minimum period of 5 years following completion of the research project.
- I have been informed that the results from this pilot study will be made available to me via email once the study has been completed, if I choose to receive a written summary of the results.
- I understand that I will be protected and remain confidential.
- All of my questions have been answered.
- The research team has verified, through an approved means, that the research participant is fully vaccinated.
- I understand that in-person research carries a greater risk for transmission of COVID-19

________________________ ________________________ ______________

(Name of Participant, Printed) (Signature of Participant) (Date)

☐I would like to receive a written summary of the results.

Email address: ______________________________

Appendix D

Physical Activity Readiness Questionnaire (PAR-Q+) Form

2021 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAMF ______ DATE ______

SIGNATURE ______ WITNESS ______

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

01-11-2020

2021 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?
If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?
If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm
If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?
If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes
If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______________________ DATE ______________________

SIGNATURE ______________________ WITNESS ______________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
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The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
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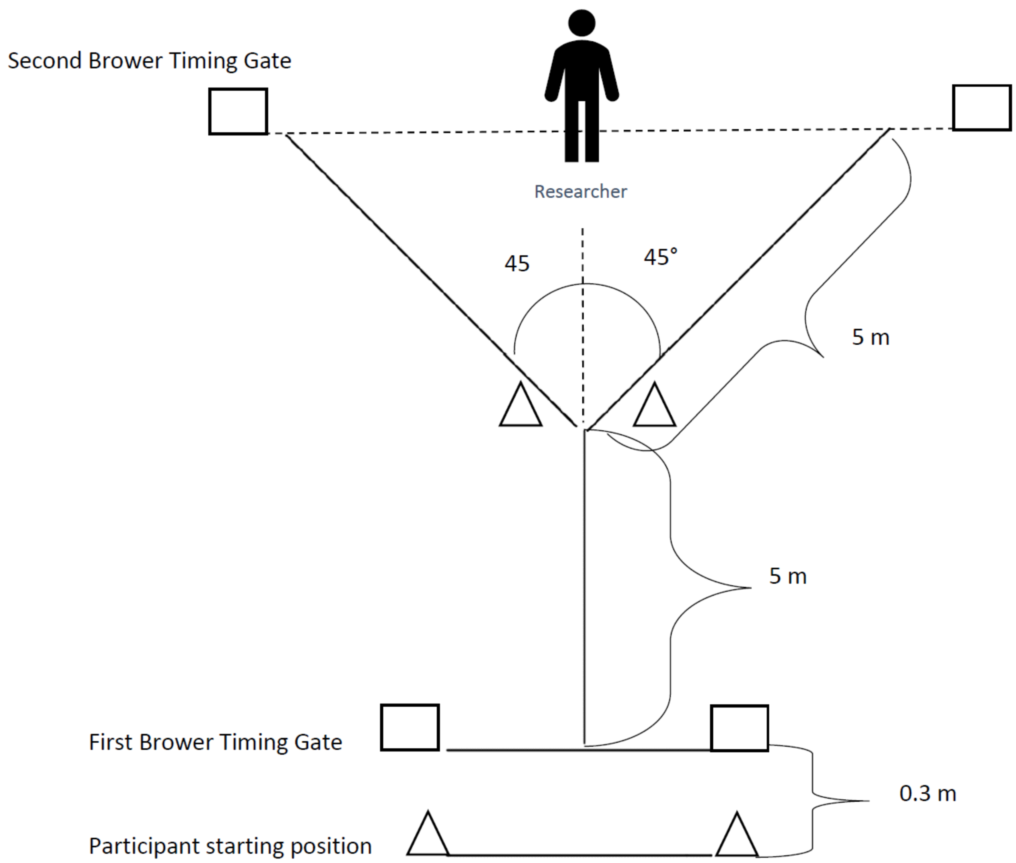
Appendix E

Diagram of the Reactive Agility Test



Appendix F

Borg Scale of Perceived Exertion

Rating	Perceived Exertion
6	No exertion
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

BORG RPE. This figure visually represents the BORG rating of perceived exertion scale. Adapted from "What is RPE and how can you use it in training?" by Running Magazine. Retrieved from https://runningmagazine.ca/sections/training/rpe-can-use-training/